



# Modeling and Simulation of Hybrid Electric Vehicles: ADVISOR and the Digital Functional Vehicle

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National Renewable Energy Laboratory



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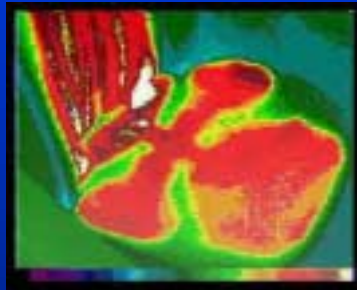


# Presentation Outline

- Background and Capabilities of ADVISOR
- Demonstration of ADVISOR 3.0
- Parametric Vehicle and First-Order Packaging
- Linking ADVISOR and ADAMS/Car



# Light-Duty Hybrid Electric Vehicle Program



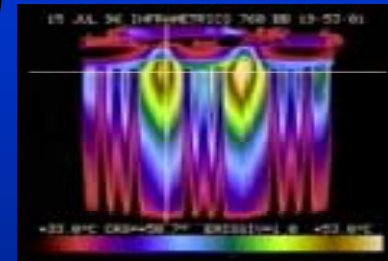
Vehicle Climate Control



Vehicle Systems Analysis



Digital Functional Vehicle



Battery Thermal Management

**Big 3 Partnership**  
(55 mpg, mid-size vehicle)

**DaimlerChrysler**



**Ford**



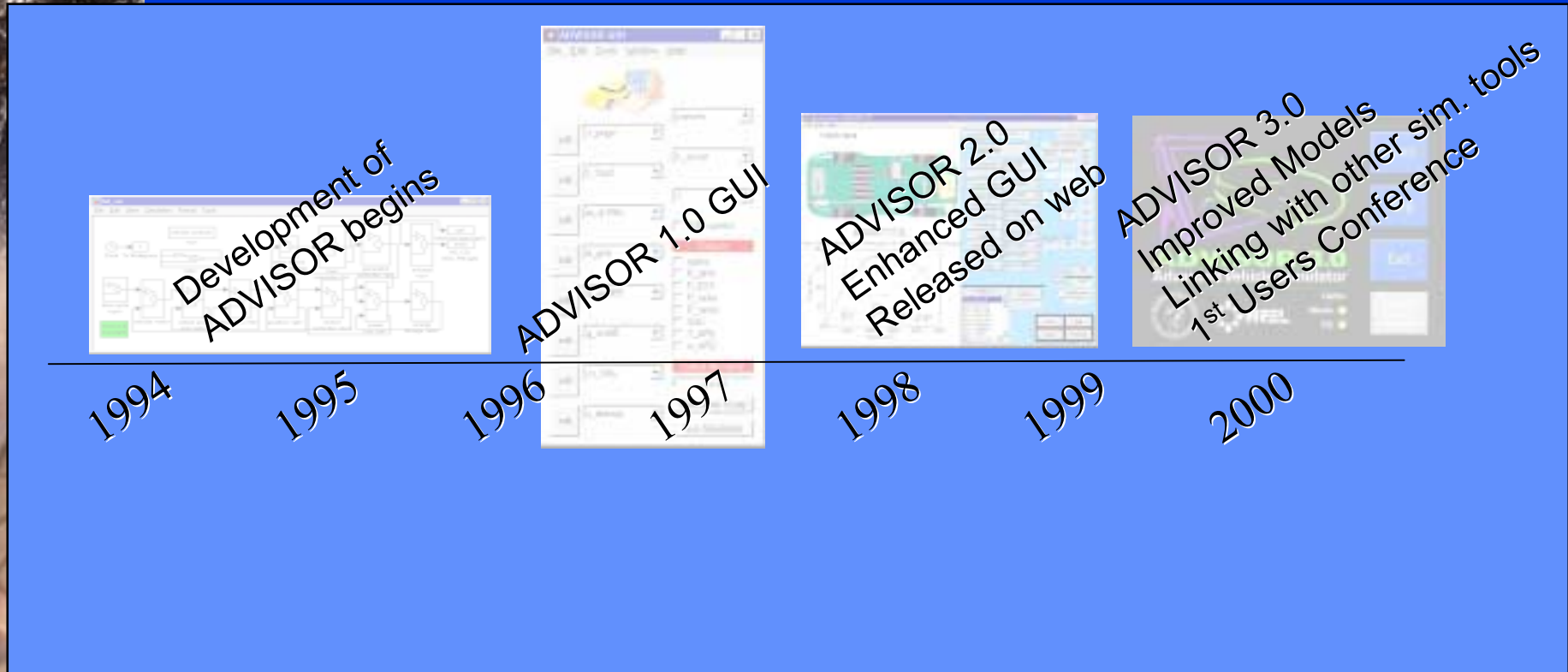
**GM**



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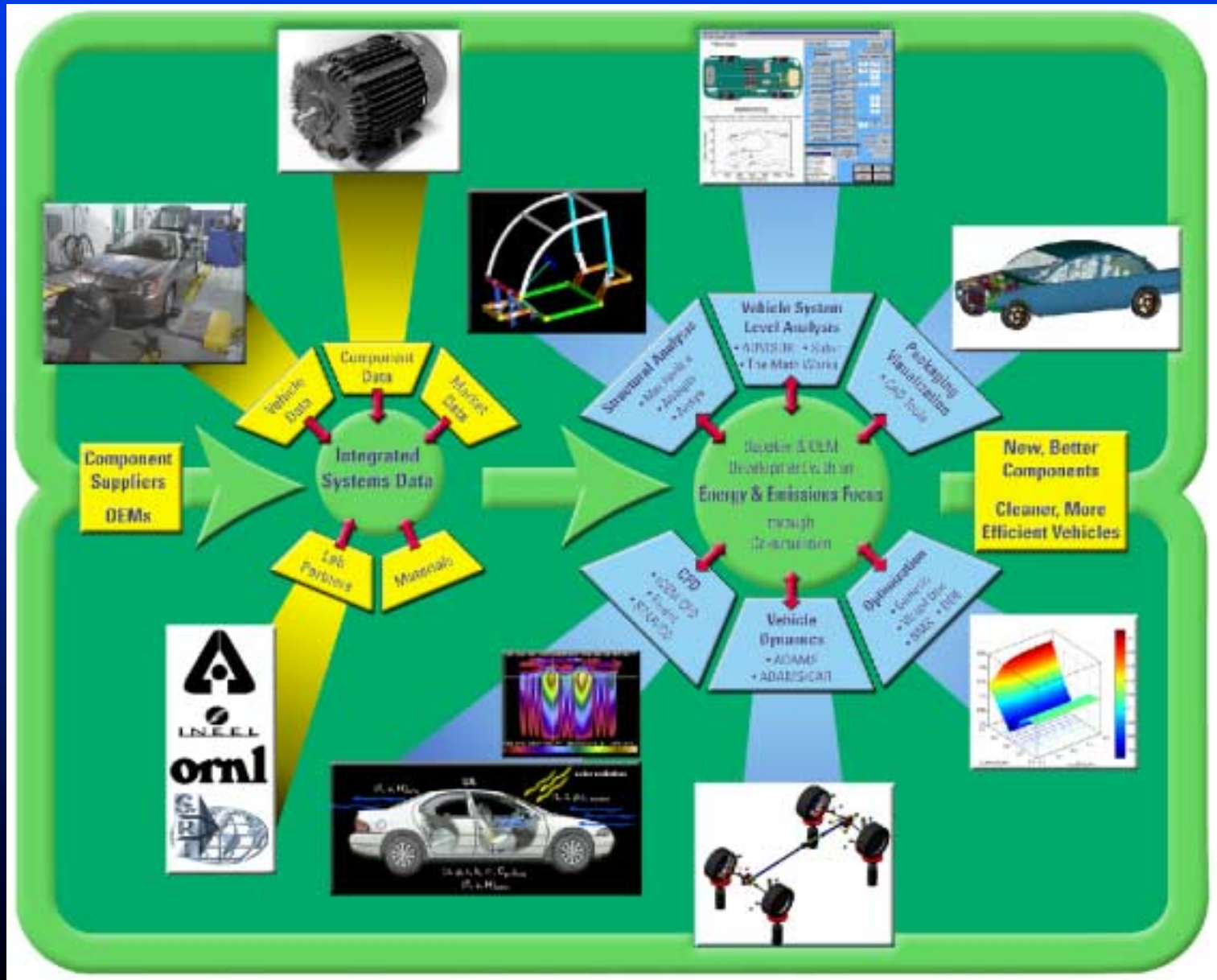


# Historical Perspective: Evolution of ADVISOR in 6 Years



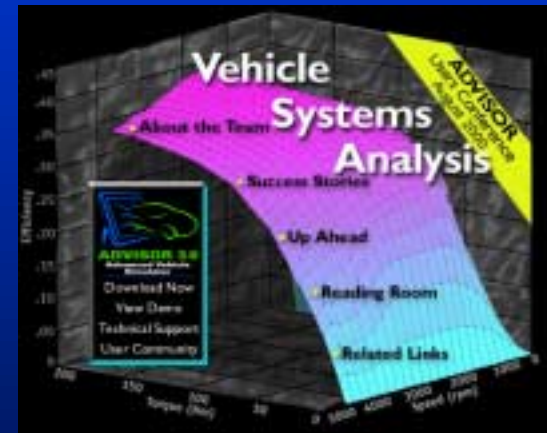


# Overall Vision: Digital Functional Vehicle



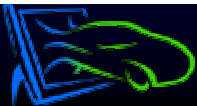
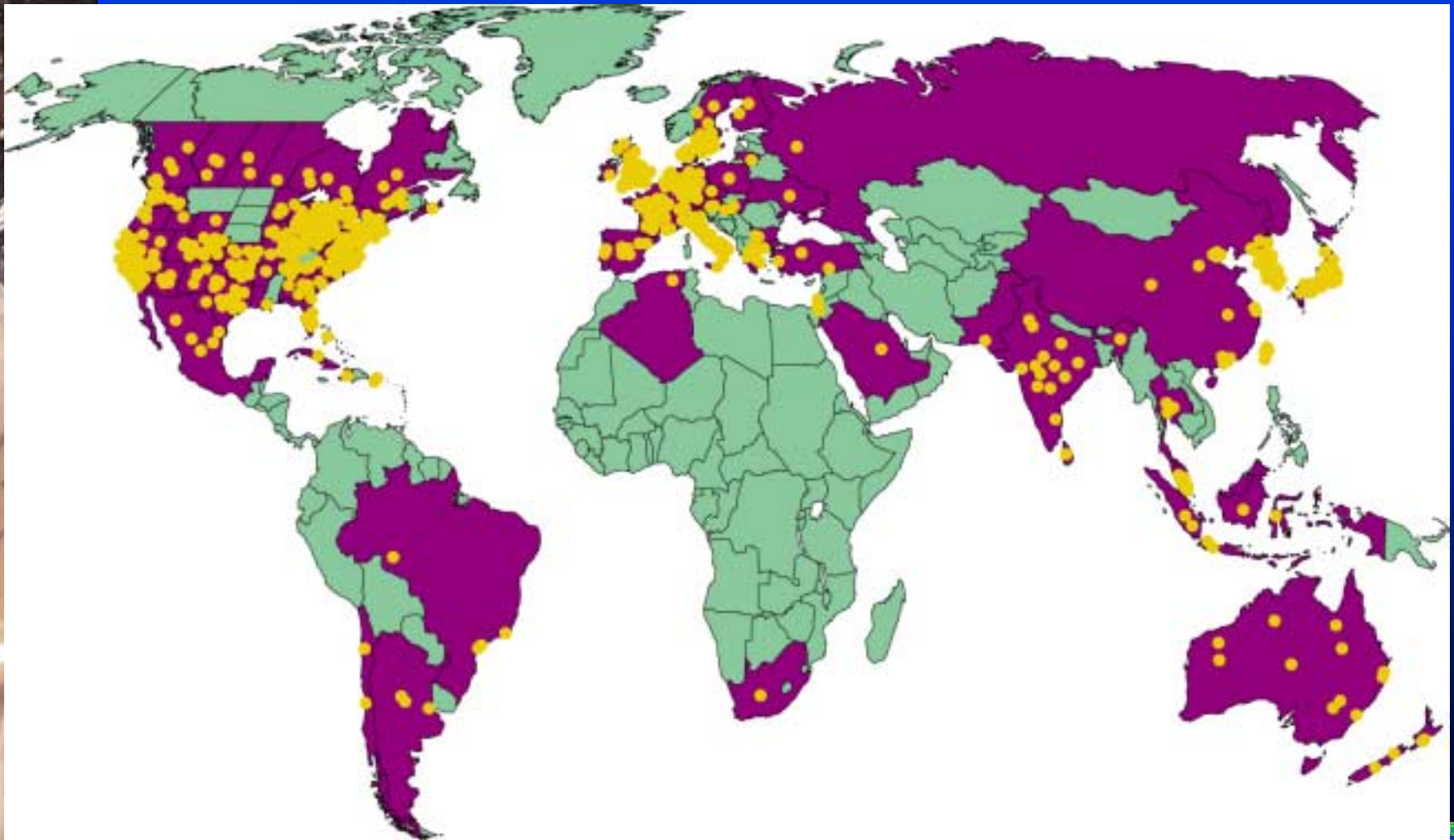
# Background on ADVISOR

- ADVISOR = ADvanced Vehicle SimulatOR
  - simulates conventional, electric, or hybrid vehicles (series, parallel, or fuel cell)
- ADVISOR was created in 1994 to support DOE Hybrid Program at NREL
- Released on vehicle systems analysis web site in September, 1998
- Downloaded by over 2000 people around world
- Users help provide component data and validation, feedback for future development



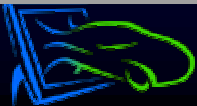
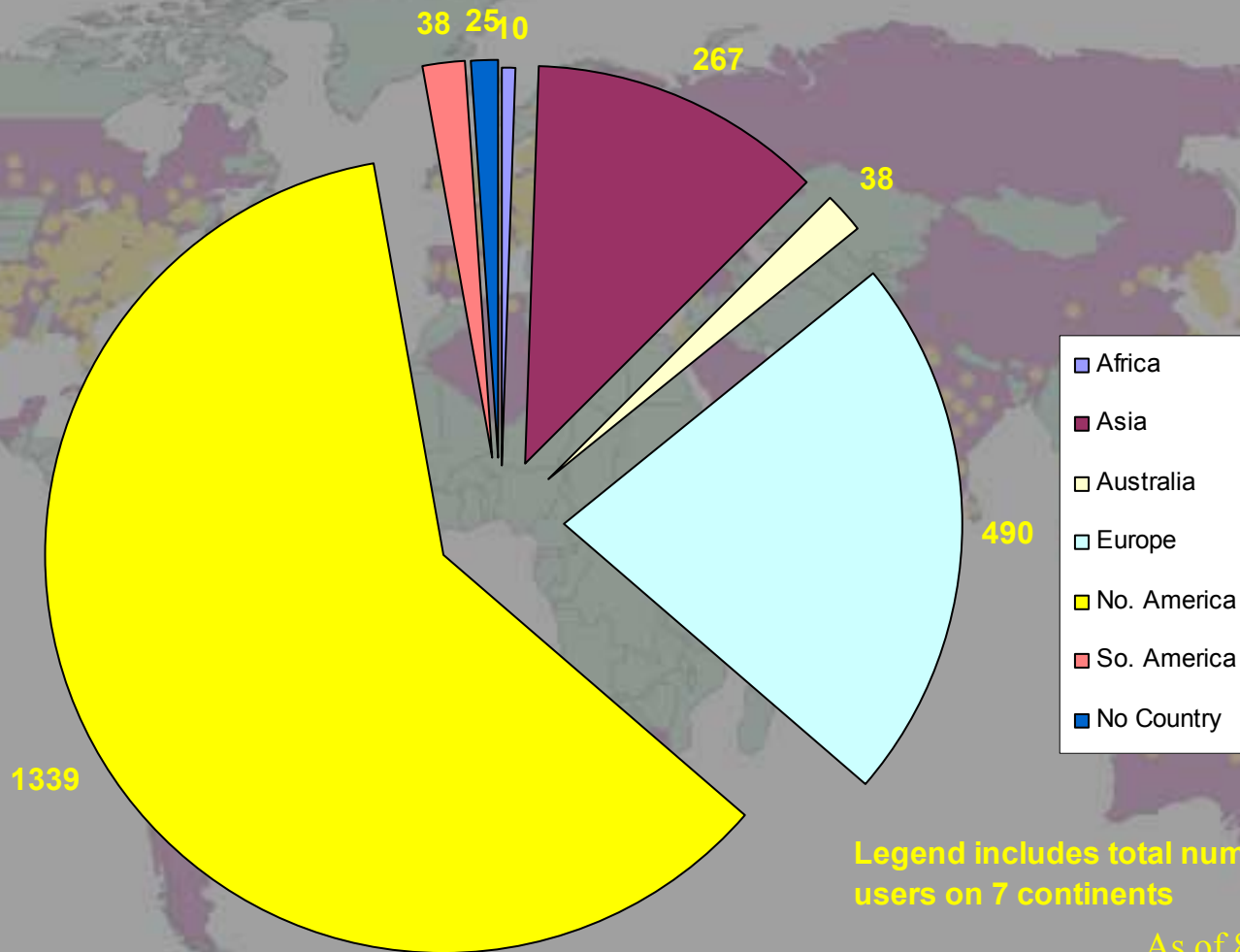
# ADVISOR Being Used Globally

August 2000: >2000 users



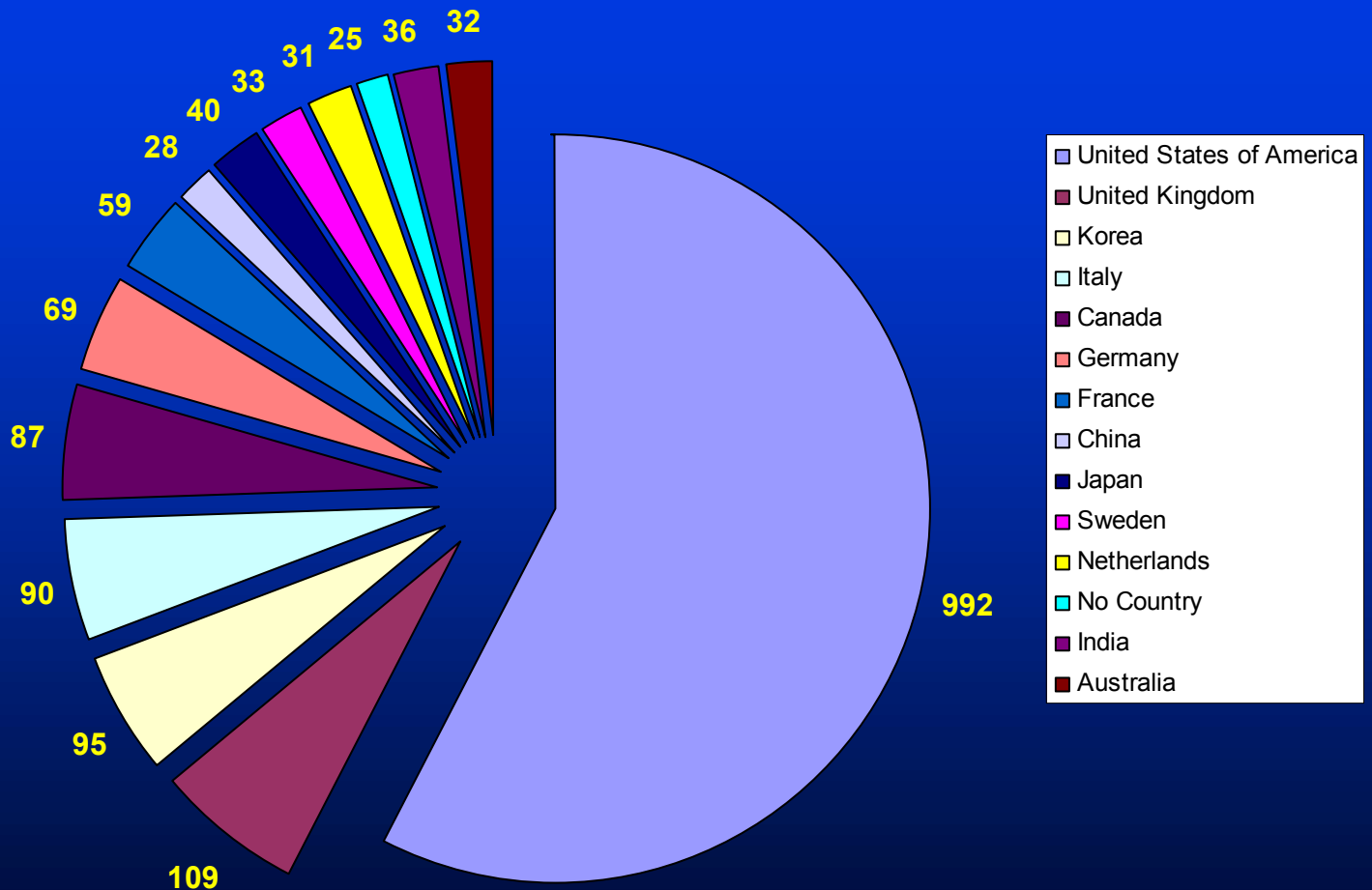


# ADVISOR Downloads by Continent





# ADVISOR Downloads by Country



Legend included countries with 25 or more users  
Total number of countries using ADVISOR = 70

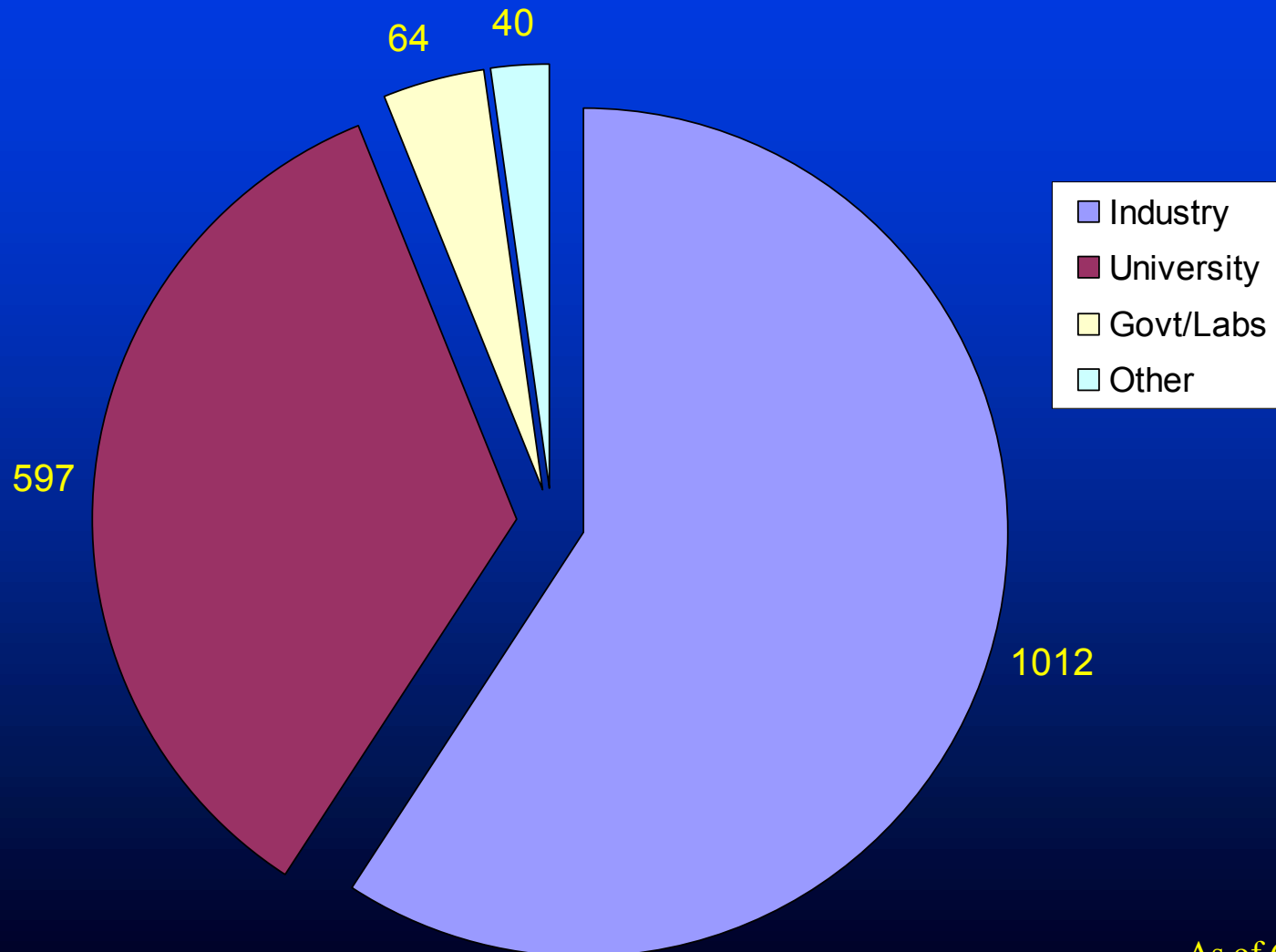
As of 8/17/00



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# ADVISOR Downloads by Type of Organization



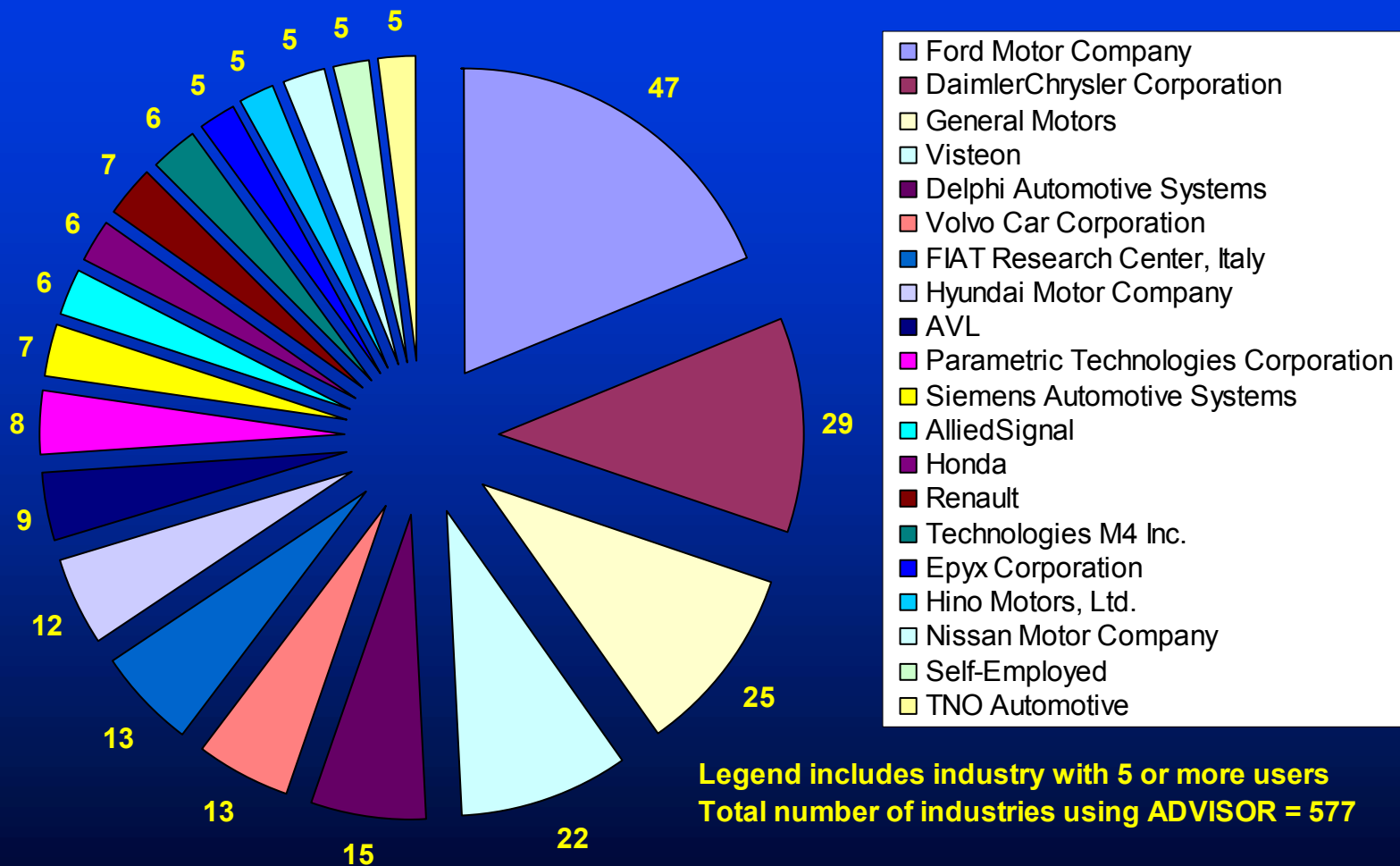
As of 6/7/00



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# ADVISOR Downloads by Industry



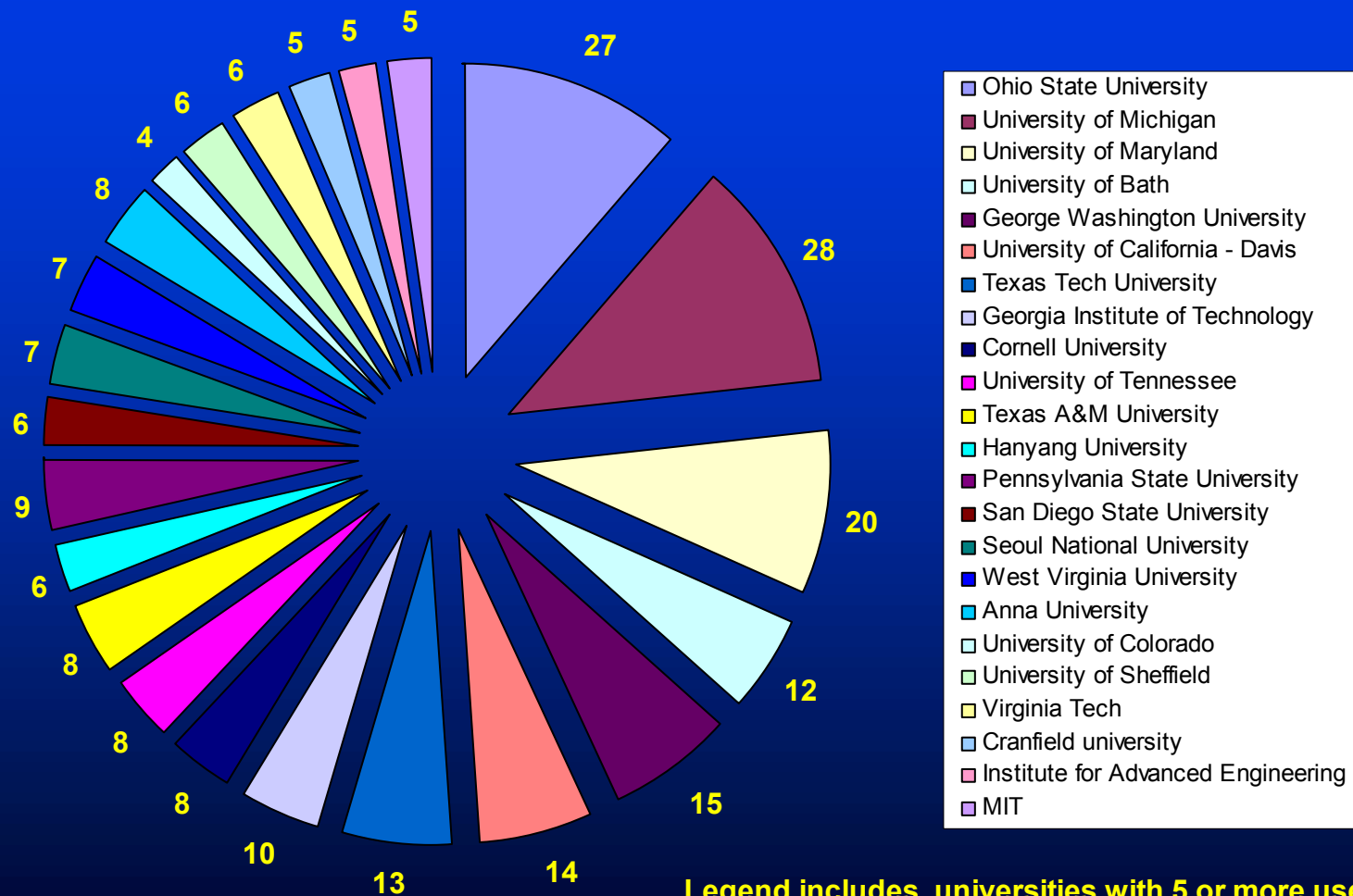
As of 8/17/00



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# ADVISOR Downloads by Universities



Legend includes universities with 5 or more users  
Total number of universities using ADVISOR = 277

As of 8/17/00

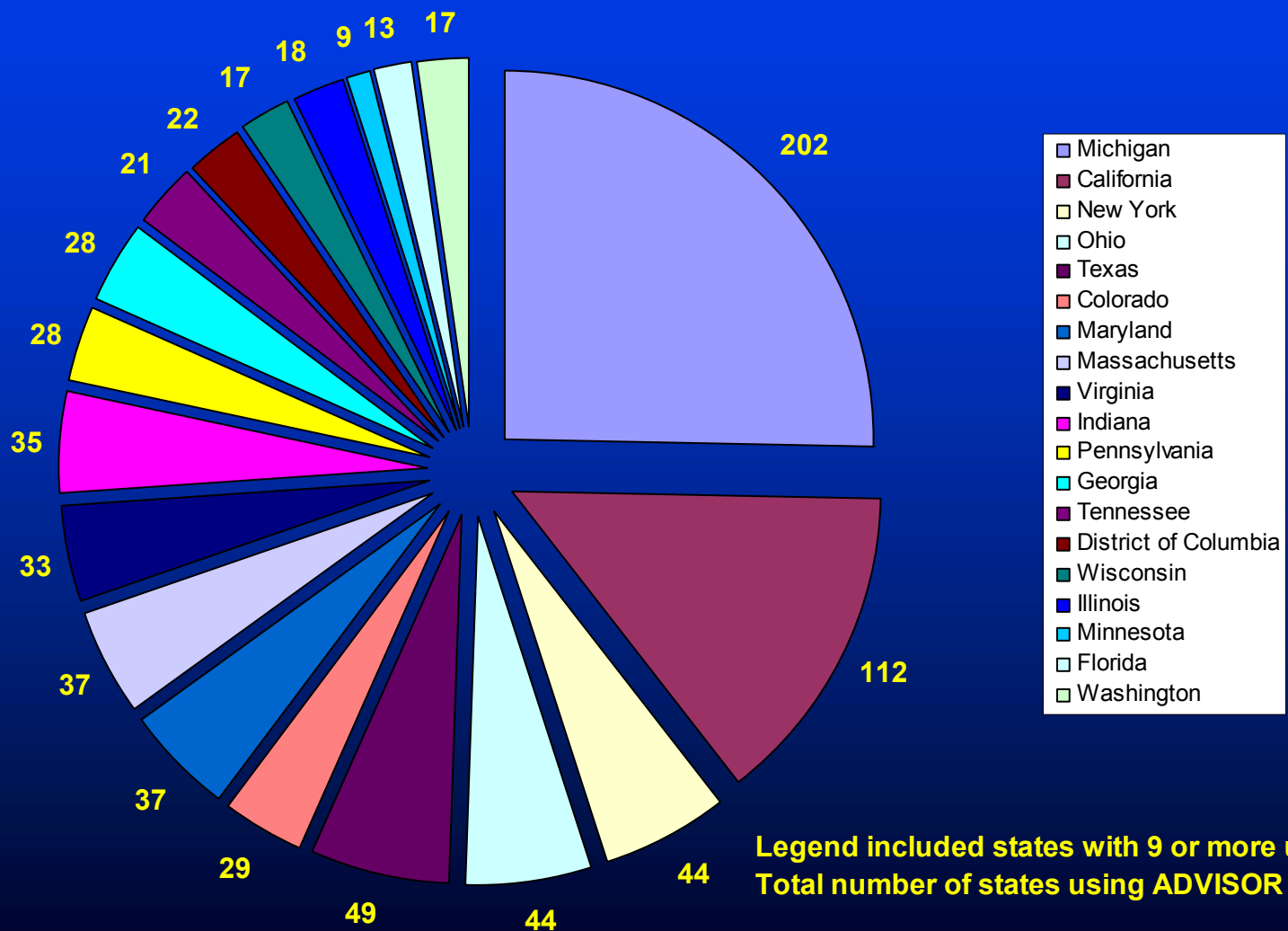


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# ADVISOR Downloads by State



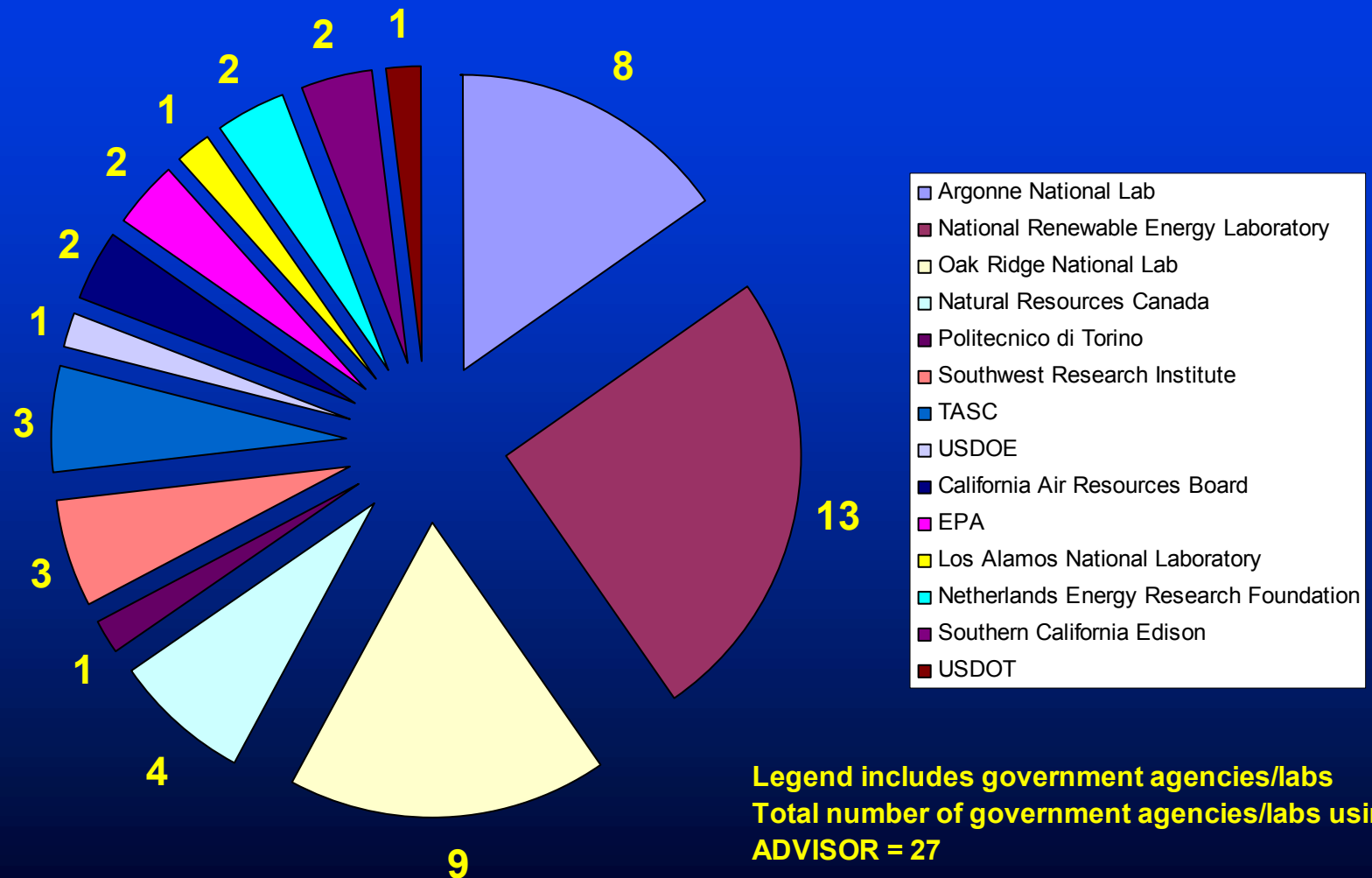
As of 8/17/00



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# ADVISOR Downloads by Government Agencies/Labs



As of 8/17/00

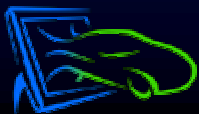
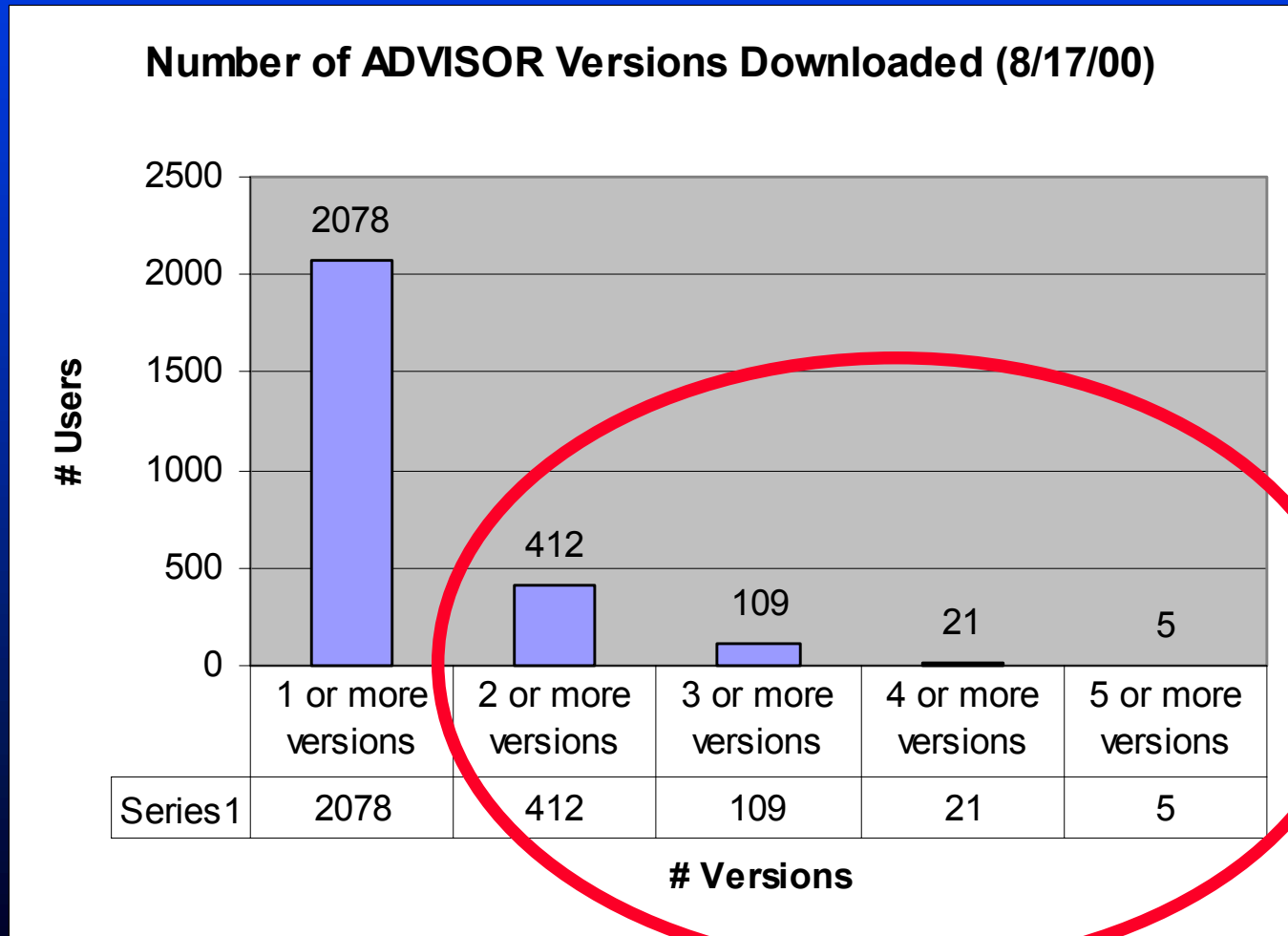


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# Multiple Versions Downloaded as one Indicator of “Active” Users

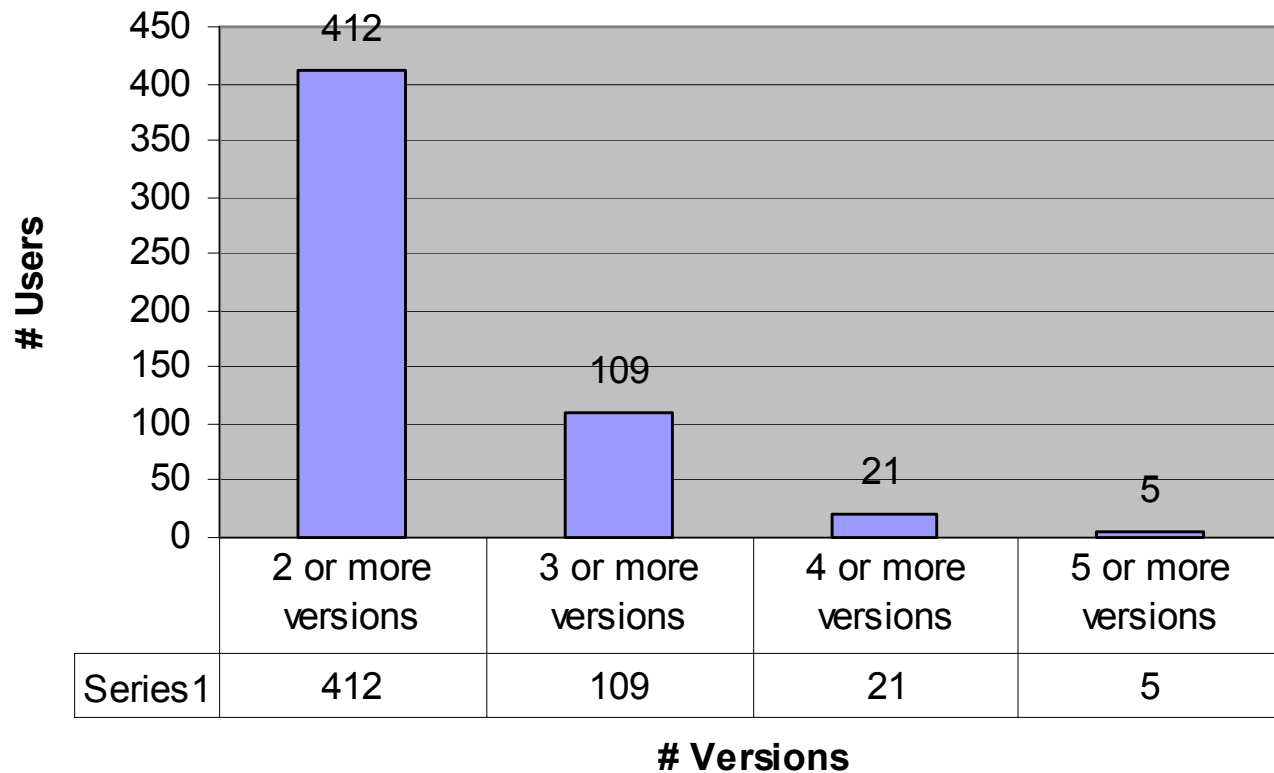
- ~20% appear to be “active” with ADVISOR



# Multiple Versions Downloaded as one Indicator of “Active” Users

- ~20% appear to be “active” with ADVISOR

Number of ADVISOR Versions Downloaded (8/17/00)





# ADVISOR Users Conference: August 2000

Systems Analysis ADVISOR - Microsoft Internet Explorer provided by NREL

File Edit View Favorites Tools Help

Address <http://www.ctts.nrel.gov/analysis/conference.html> Go

**ADVISOR** About the Team Success Stories Up Ahead Reading Room Related Links  **Vehicle Systems Analysis**

[Download Now](#) [View Demo](#) [Technical Support](#) [User Community](#)

## ADVISOR Users Conference



- date** - August 24-25, 2000
- location** - Costa Mesa, CA, [click here for a map](#)
- general info** - [get more information about the conference](#)
- call for papers** - [get more information about possible paper or presentation topics](#)
- schedule** - [timeline for abstract submittal, notification, and conference](#)
- travel** - [hotel, airport](#)
- sponsorship** - [we're looking for sponsors, check here for more information](#)
- program** - [conference program](#) **\*\*Updated\*\***



# ADVISOR Users Conference: Program

Program	
Thursday, August 24, 2000	
8:15	Registration & Continental Breakfast
9:00	Opening Address -Keith Wipke, National Renewable Energy Laboratory
9:15	Partnering with the Auto Industry The Rapid Development of an Electric Vehicle -Andreas Vlahinos, David Rush, Transportation, Design & Manufacturing CO Co-Simulation of ADVISOR and Saber - A solution for total vehicle energy management simulation -John MacBain, Delphi Automotive Comparison of fuel efficiencies and fuel flexibility of small automotive vehicles -Robert Apter, John Reuyl, NEVCOR
10:45	Break
11:00	Cosimulation: Partnering with the Software Industry I Optimization and Thermal Modeling Implementing Optimization in ADVISOR Using the VisualDOC API -John Garcelon, Vanderplaats Research & Development Detailed Vehicle Thermal Systems Modeling in ADVISOR through Integration with Flowmaster2 -Jason Burke, Flowmaster
12:00	Lunch, Poster sessions
13:30	DOE perspective on ADVISOR -Bob Kast, Department of Energy
14:00	HIL and Forward-Looking Simulations Coupled with ADVISOR Using Models for Hardware-in-the-Loop (HIL) and Systems Studies -Mike Duoba, Argonne National Laboratory A Design Methodology for Diesel-Based Hybrid Powertrains -George Delagrammatikas, Dennis Assanis, University of Michigan
15:00	Break
15:15	New Concepts from Universities A hybrid-propulsion powertrain with planetary gear set: simulation results and a design approach -Marco Santoro, Dresden University of Technology, Leone Martellucci, University of Rome Use of ADVISOR for simulation of a Hybrid Electric Vehicle with a Stirling Engine as the Auxiliary Power Unit -Luis Figueroa, University of Calgary Development of an ADVISOR Simulation Model for GW FutureTruck Vehicle -Mohd-Syaifuddin Mohd, George Washington University
16:45	Q&A with the ADVISOR team Moderator Terry Penney, NREL
17:30	Reception and Banquet Keynote Presentation: Toyota's US Prius-Mark Amstock, Toyota
Friday, August 25, 2000	
8:00	Continental Breakfast
8:30	Validation, Vehicle Development, and Applications Simulations of heavy-duty transit buses -Alain Julien, Jean Bevard, Alstom



# Three Main ADVISOR Screens (Roadmap)

## Vehicle Input



## Simulation Setup



## Results





# ADVISOR Demonstration



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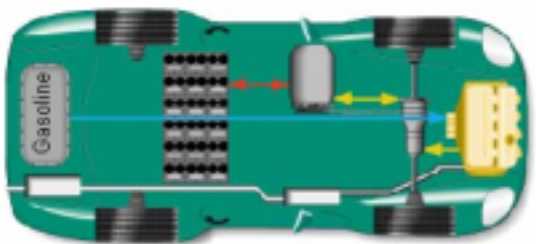




# Vehicle Input Screen

**Vehicle Input--ADVISOR 3.0**  
File Edit Units Model Help

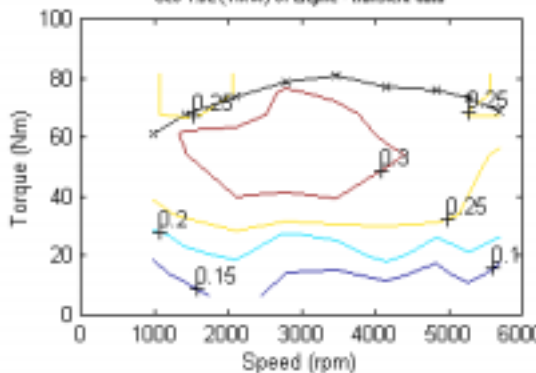
## Vehicle Input



Motor1 Position:  Motor2 Position:

fc\_efficiency:

Fuel Converter Operation  
Geo 1.8L (41kW) SI Engine - transient data



Load File:

Drivetrain Config:

	version	type		Auto-Size
<input checked="" type="checkbox"/> Vehicle	<input type="text" value="v01"/>	<input type="text" value="si"/>	VEH_SMCAR	592
<input checked="" type="checkbox"/> Fuel Converter	<input type="text" value="v01"/>	<input type="text" value="si"/>	FC_SI41_emis	41 0.34 131
<input checked="" type="checkbox"/> Exhaust Aftertreat	<input type="text" value="v01"/>	<input type="text" value="si"/>	EX_SI	#of V nom 11
<input checked="" type="checkbox"/> Energy Storage	<input type="text" value="v01"/>	<input type="text" value="pb"/>	ESS_FB25	25 308 275
Energy Storage 2	<input type="text" value="v01"/>	<input type="text" value="pb"/>	ess 2 options	
<input checked="" type="checkbox"/> Motor	<input type="text" value="v01"/>	<input type="text" value="pb"/>	MC_AC75	75 0.92 91
Motor 2	<input type="text" value="v01"/>	<input type="text" value="pb"/>	motor 2 options	
Starter	<input type="text" value="v01"/>	<input type="text" value="pb"/>	starter options	
<input checked="" type="checkbox"/> Generator	<input type="text" value="v01"/>	<input type="text" value="pb"/>	GC_ET492	
<input checked="" type="checkbox"/> Transmission	<input type="text" value="v01"/>	<input type="text" value="man"/>	TX_5SPD	0.95 114
Transmission 2	<input type="text" value="v01"/>	<input type="text" value="man"/>	trans 2 options	
Clutch/Torq. Conv.	<input type="text" value="v01"/>	<input type="text" value="man"/>	clutch/torque converter c	
<input checked="" type="checkbox"/> Torque Coupling	<input type="text" value="v01"/>	<input type="text" value="man"/>	TC_DUMMY	1
<input checked="" type="checkbox"/> Wheel/Axle	<input type="text" value="v01"/>	<input type="text" value="man"/>	WH_SMCAR	0
<input checked="" type="checkbox"/> Accessory	<input type="text" value="v01"/>	<input type="text" value="man"/>	ACC_HYBRID	
Acc Electrical	<input type="text" value="v01"/>	<input type="text" value="man"/>	acc elec options	
<input checked="" type="checkbox"/> Powertrain Control	<input type="text" value="v02"/>	<input type="text" value="man"/>	PTC_PAR	

Cargo:

Calculated Mass:

☐ override mass

Save Help

Back Continue

Variable List Current Value

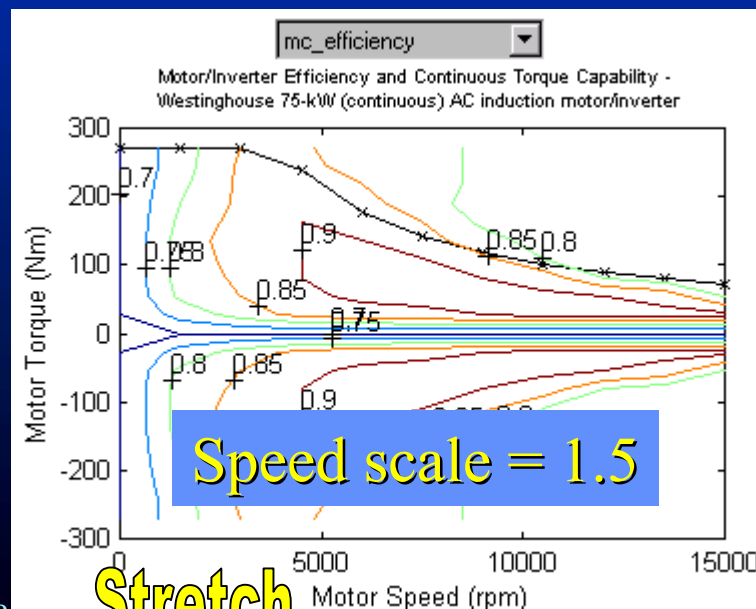
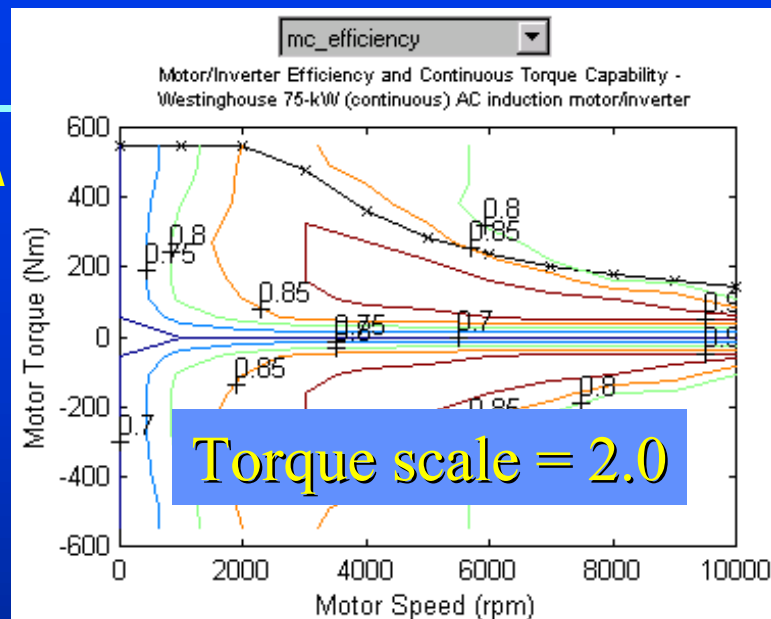
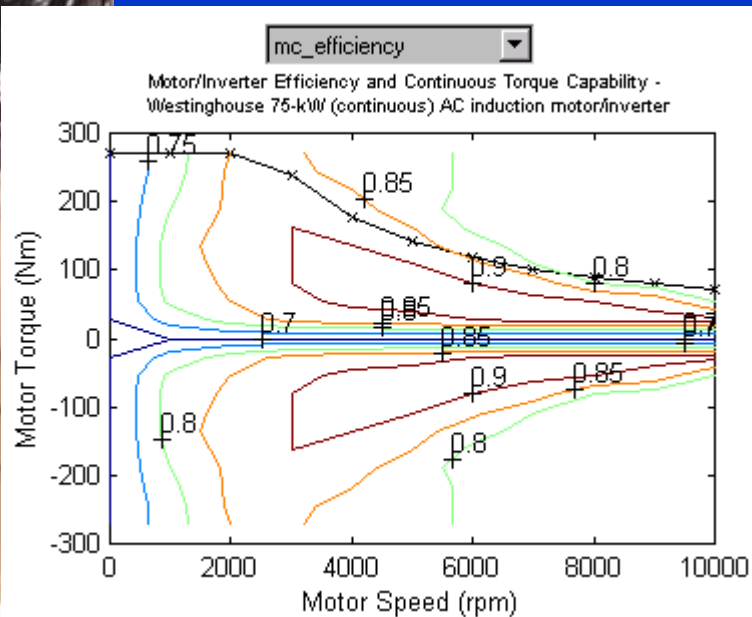
Edit Var:



# Current ADVISOR scaling algorithm is linear (motors and engine)

Original Data Map

Stretch



Stretch



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# Vehicle Input Screen, Autosize Function

**Autosize Configuration Window**

**Autosize Method Selection**

☒ Autosize using Matlab ☐ Autosize using VisualDOC

**Constraints**

☒ Grade

Goal	Tolerance (+/-)
Speed(mph) 55	0.01
Grade(%) 6	0.05

☒ Acceleration

Goal	Tolerance (+/-)
<input type="checkbox"/> 0-18mph (0-29km/h) (s) 3.5	0.02
<input type="checkbox"/> 0-30mph (0-48km/h) (s) 10	0.02
<input checked="" type="checkbox"/> 0-60mph (0-97km/h) (s) 12	0.02
<input checked="" type="checkbox"/> 40-60mph (64-97km/h) (s) 5.3	0.02
<input checked="" type="checkbox"/> 0-85mph (0-137km/h) (s) 23.4	0.05
Vehicle maximum speed (mph) 90	

**Design Variables**

Variable Name	Initial Value	Candidate Values	
<input checked="" type="checkbox"/> Fuel Converter (kW)	41	31	62
<input checked="" type="checkbox"/> ESS (# modules)	25	19	38
<input checked="" type="checkbox"/> Motor Size (kW)	75	56	112
<input type="checkbox"/> Low SOC (-)			
<input type="checkbox"/> High SOC (-)			

**Objectives**

☒ Component Sizes (Minimize)

☐ Vehicle Mass (Minimize)

☐ City/Hwy Combined Fuel Economy (Maximize)

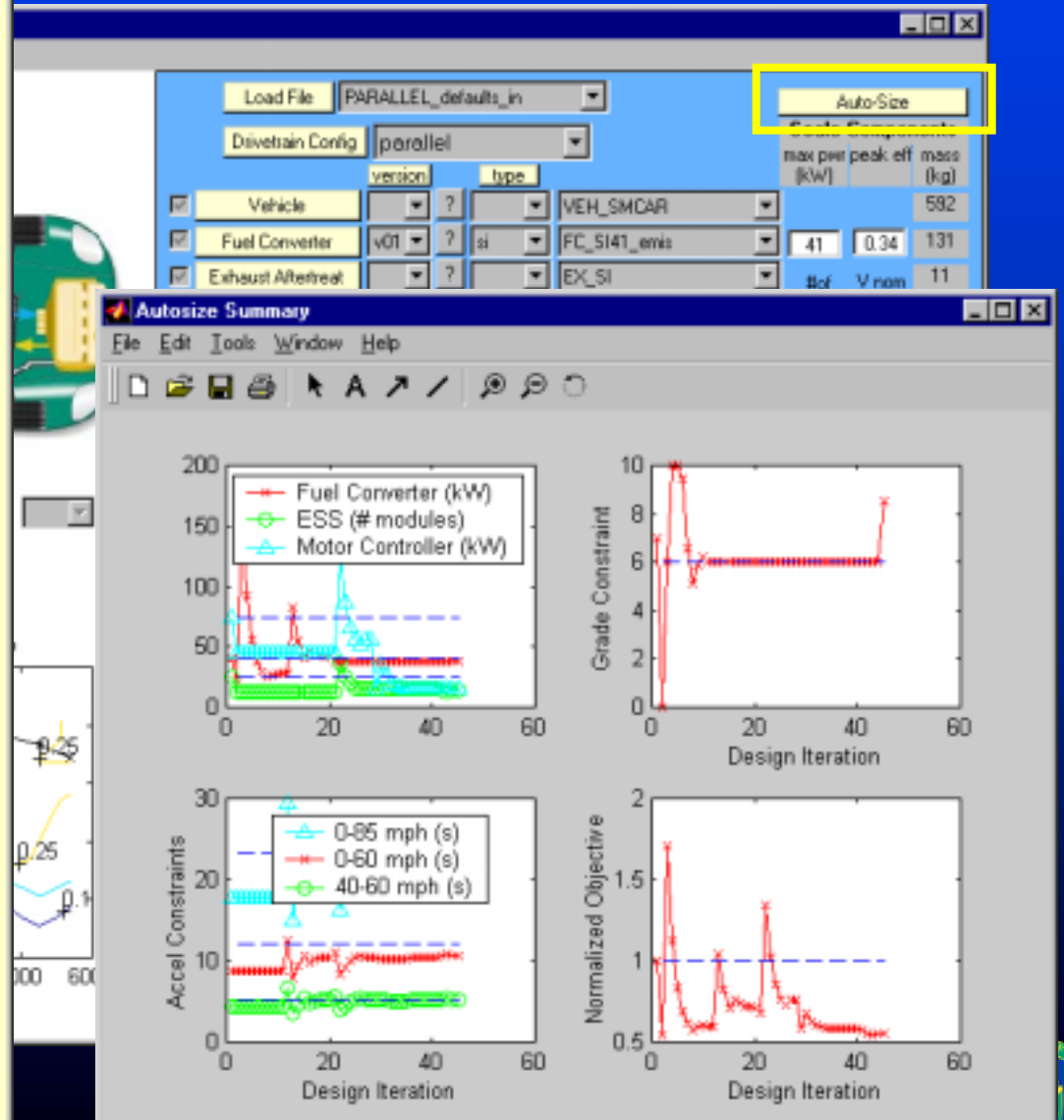
**VisualDOC Optimization Parameters**

Design Cycles: Min  Max

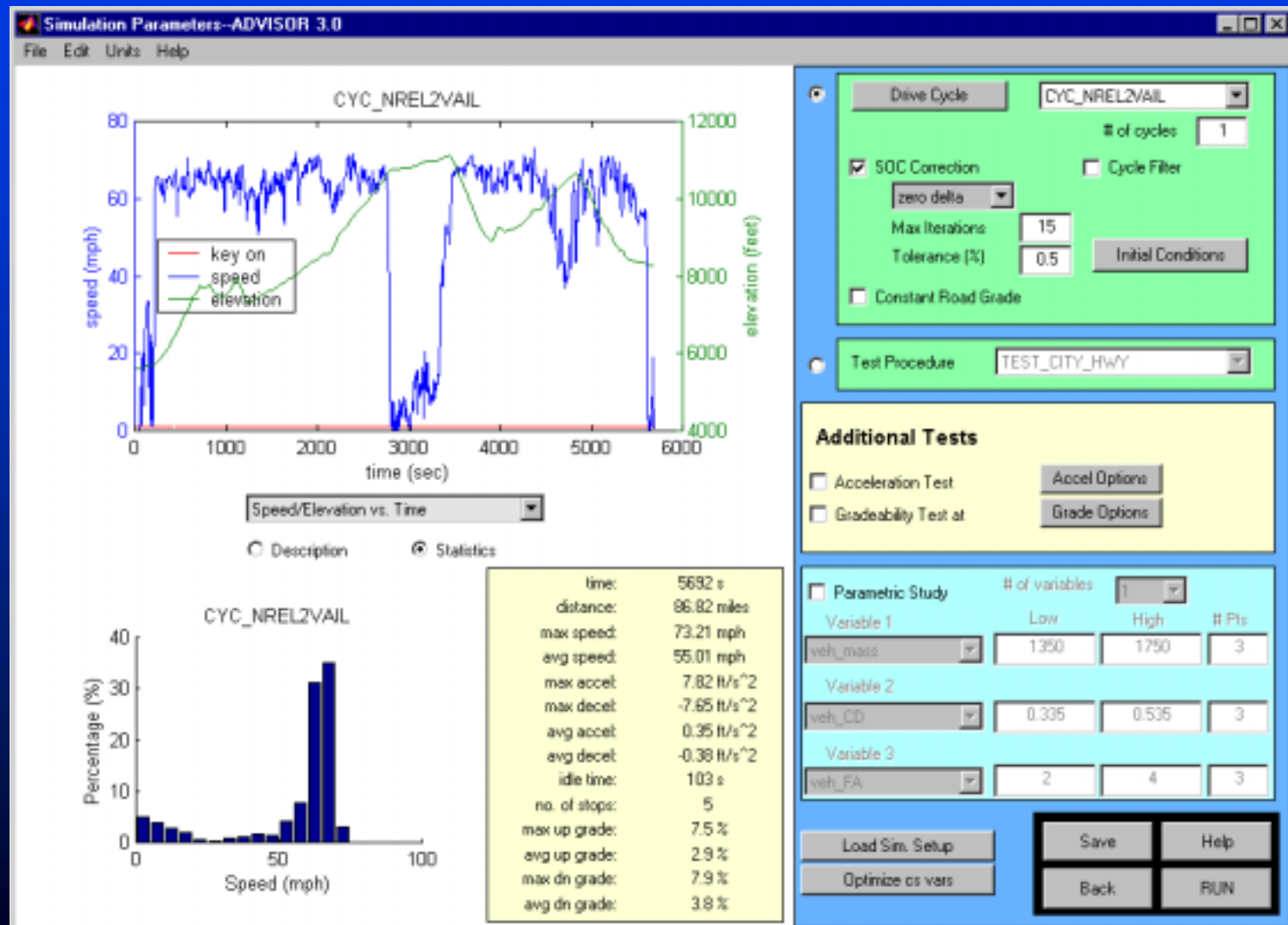
Optimization Method: ☒ Feasible Directions ☐ SLP ☐ SQP

\*\* Response surface approximations method will be used.

**RUN** **DEFAULTS** **CANCEL** **HELP**



# Simulation Setup Screen





# Simulation Setup Screen

### Simulation Parameters--ADVISOR 3.0

File Edit Units Help

Speed (mph) vs. Elevation (feet) for CYC\_NREL2VAIL

### Control Strategy Optimization Setup Window

Control Strategy Optimization Method Selection

☐ Optimize using Matlab ☒ Optimize using VisualDOC

Cycle/Test Procedure Selection

☒ Drive Cycle: **CYC\_FUDS** ☐ Test Procedure: **TEST\_CITY\_HWY**

Design Variables						
Variable Name	Units	Initial Condition	Lower Bound	Upper Bound	# Points 1st Sweep	# Points 2nd Sweep
<input checked="" type="checkbox"/> cs_lo_soc	(-)	0.4	0.1	0.5	4	3
<input checked="" type="checkbox"/> cs_hi_soc	(-)	0.8	0.55	1	4	3
<input checked="" type="checkbox"/> cs_charge_pwr	(W)	0	1000	20503.51	4	3
<input checked="" type="checkbox"/> cs_min_pwr	(W)	20503.51	1000	20503.51	4	3
<input checked="" type="checkbox"/> cs_max_pwr	(W)	20503.51	20503.51	41007.03	4	3
<input checked="" type="checkbox"/> cs_max_pwr_rise_rate	(W/s)	0	1	5000	4	3
<input checked="" type="checkbox"/> cs_max_pwr_fall_rate	(W/s)	0	-5000	-1	4	3
<input checked="" type="checkbox"/> cs_min_off_time	(s)	inf	0	200	4	3
<input checked="" type="checkbox"/> cs_fc_init_state	(boolean)	0	0	1	1	1

#### Objectives/Constraints

OBJ CON	Weighting Factor (0-1)	Value
<input checked="" type="radio"/> CO Emissions (Minimize,g/mi)	1	1.7
<input checked="" type="radio"/> HC Emissions (Minimize,g/mi)	1	0.125
<input checked="" type="radio"/> NOx Emissions (Minimize,g/mi)	1	0.4
<input checked="" type="radio"/> PM Emissions (Minimize,g/mi)	1	-1
<input checked="" type="radio"/> Fuel Economy (Maximize,mpg)	1	80

#### VisualDOC Parameters

Buttons: RUN, DEFAULTS, CANCEL, HELP

Drive Cycle: **CYC\_NREL2VAIL**

# of cycles: **1**

☒ SOC Correction ☐ Cycle Filter

zero delta

Max iterations: **15**

Tolerance (%): **0.5**

☐ Constant Road Grade

Initial Conditions

Test Procedure: **TEST\_CITY\_HWY**

### Additional Tests

☐ Acceleration Test **Accel Options**

☐ Gradesability Test at **Grade Options**

☐ Parametric Study # of variables: **1**

Variable	Low	High	# Pts
veh_mass	1350	1750	3
veh_CD	0.335	0.535	3
veh_FA	2	4	3

Load Sim. Setup

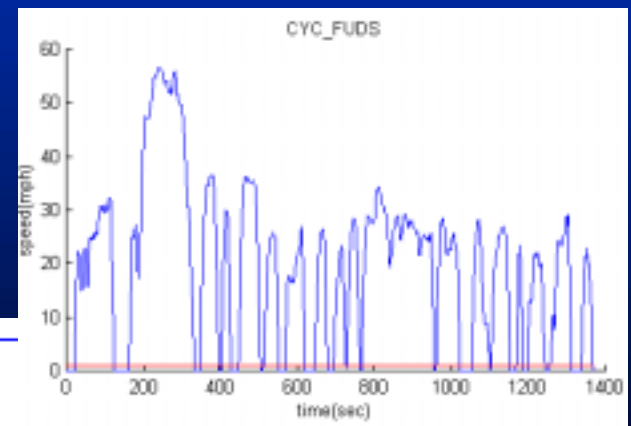
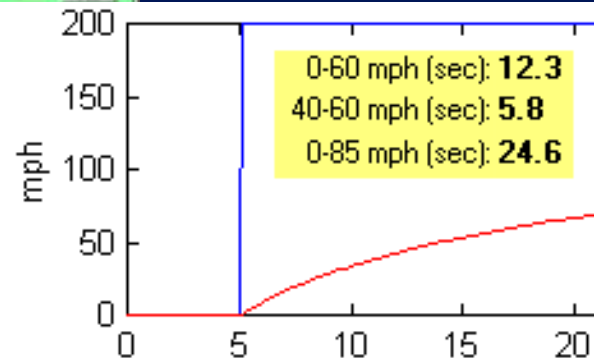
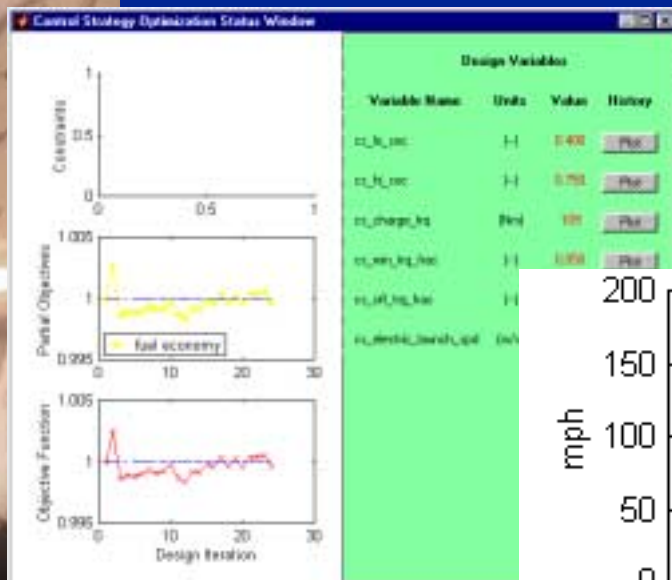
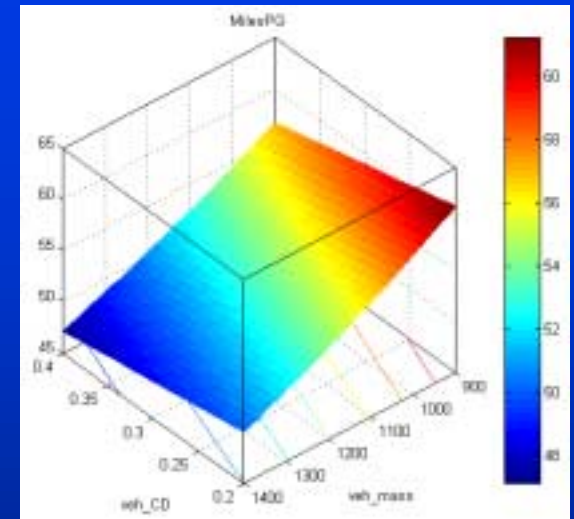
**Optimize cs vars**

Save, Help, Back, RUN

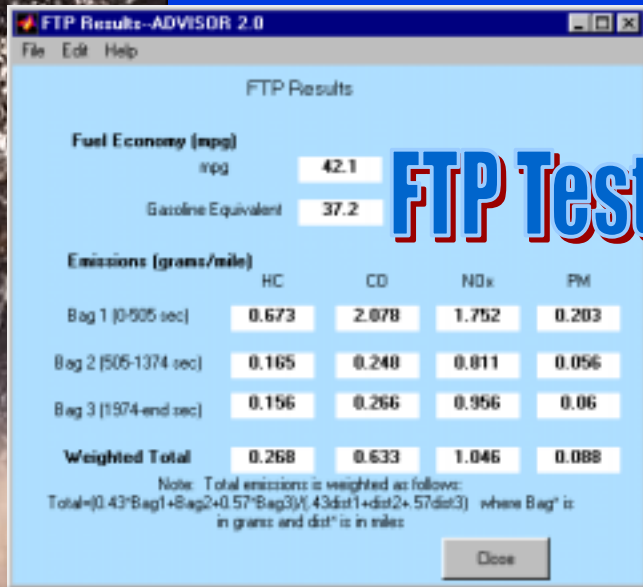


# Types of Simulation Tests Possible

- Parametric sweeps
- Drive cycles
- Acceleration and grade tests
- Control Strategy Optimizations

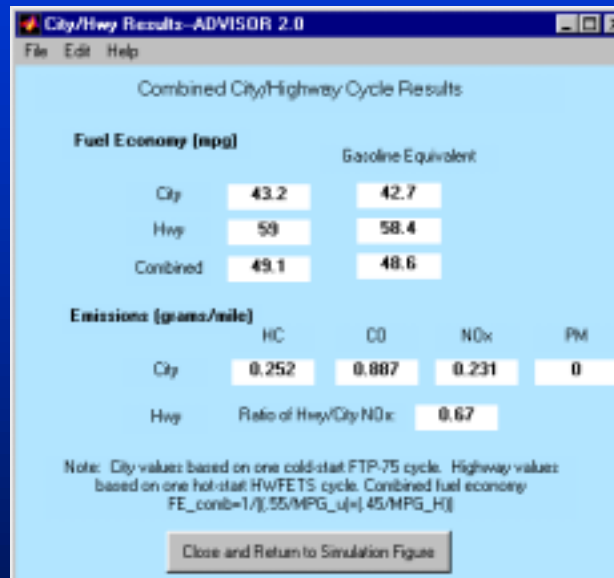


# “Test Procedures” Currently Available

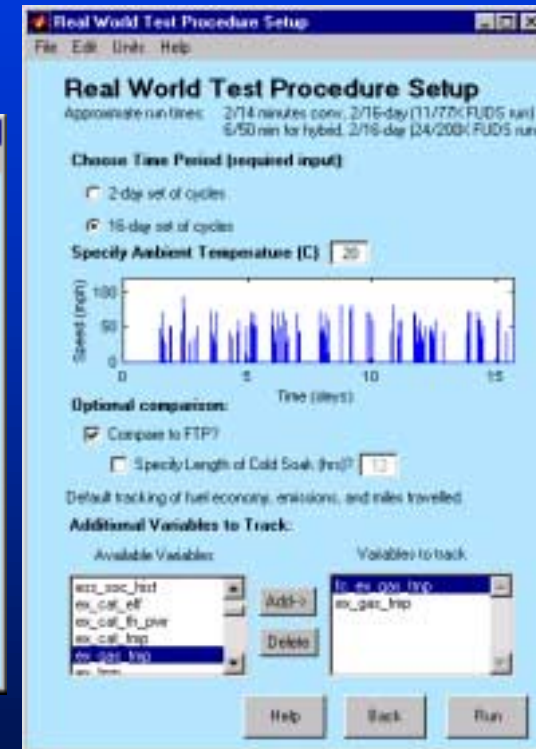


**FTP Test**

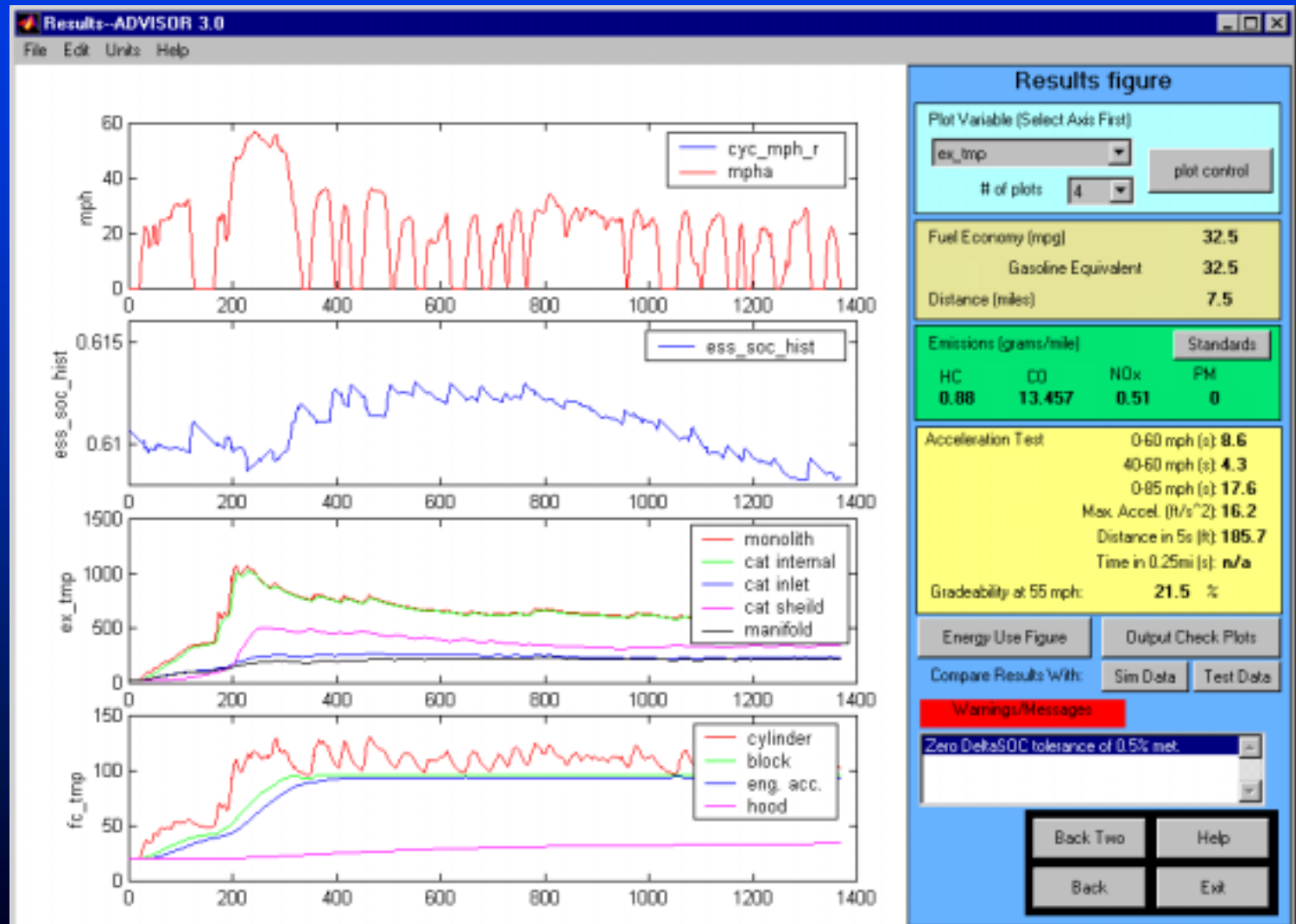
**Combined City/Highway**



**Real World**

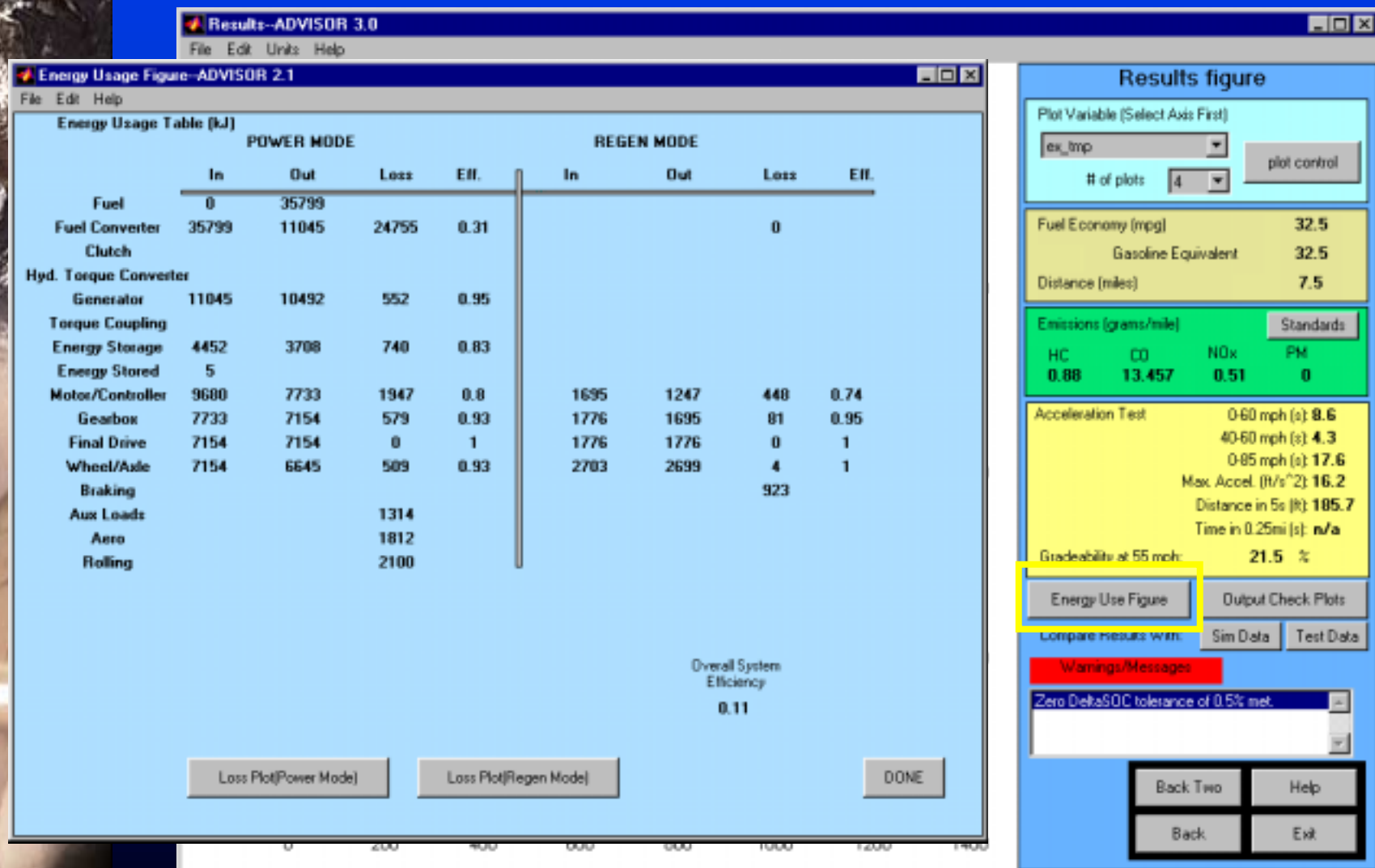


# Cycle Results Screen



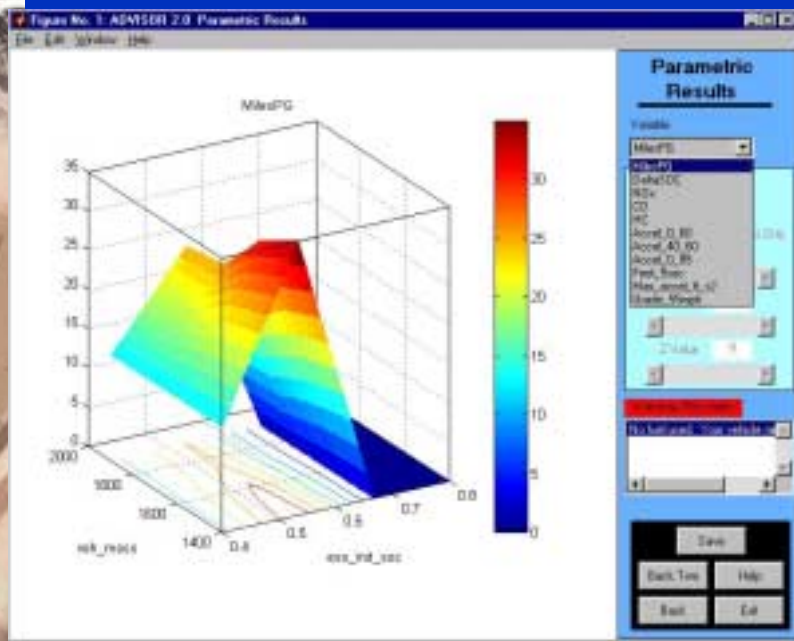


# Cycle Results Screen, Energy Usage Figure

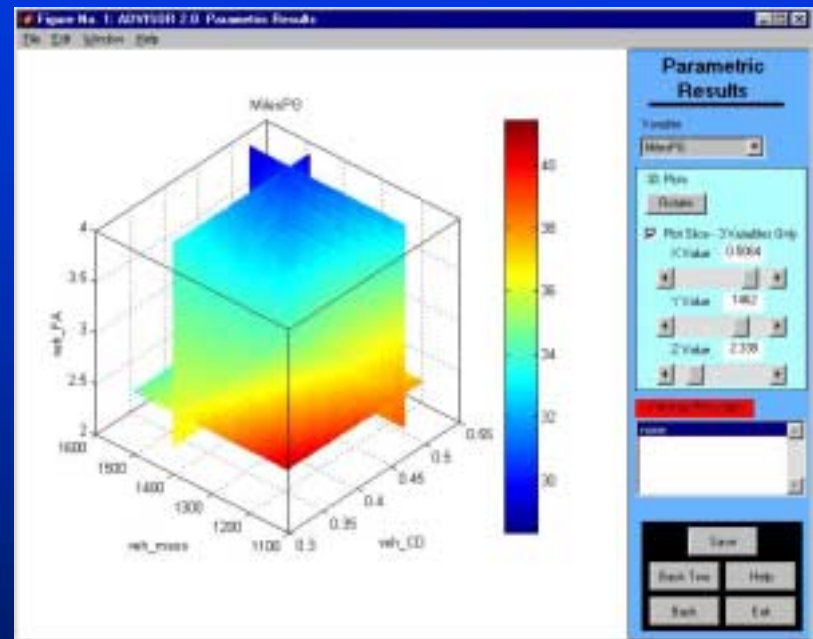


# Parametric Results: 2D and 3D

Fuel economy, emissions, acceleration times, or achieved grade as a function of your chosen variables can be displayed



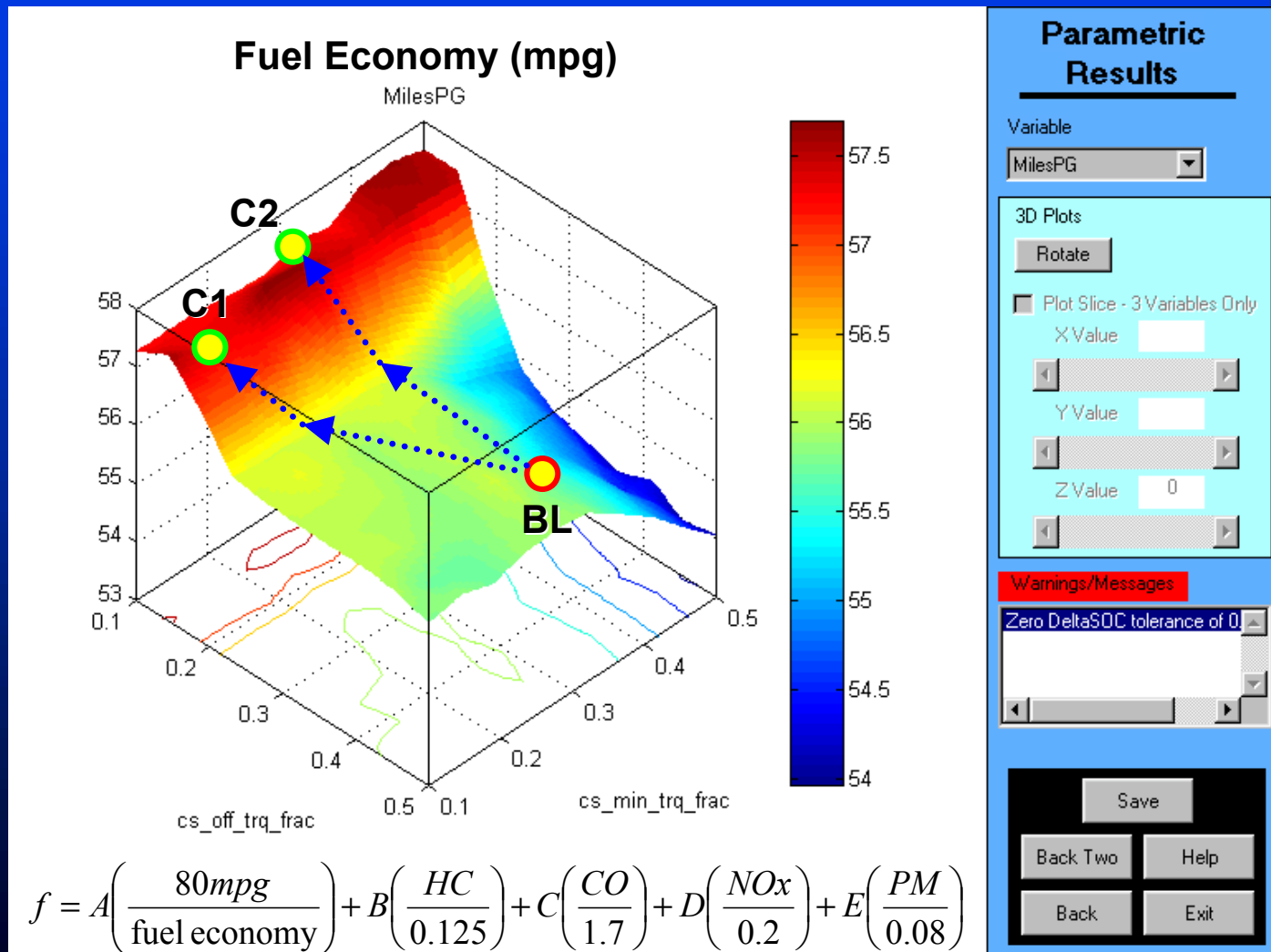
2 Variable Parametric Study



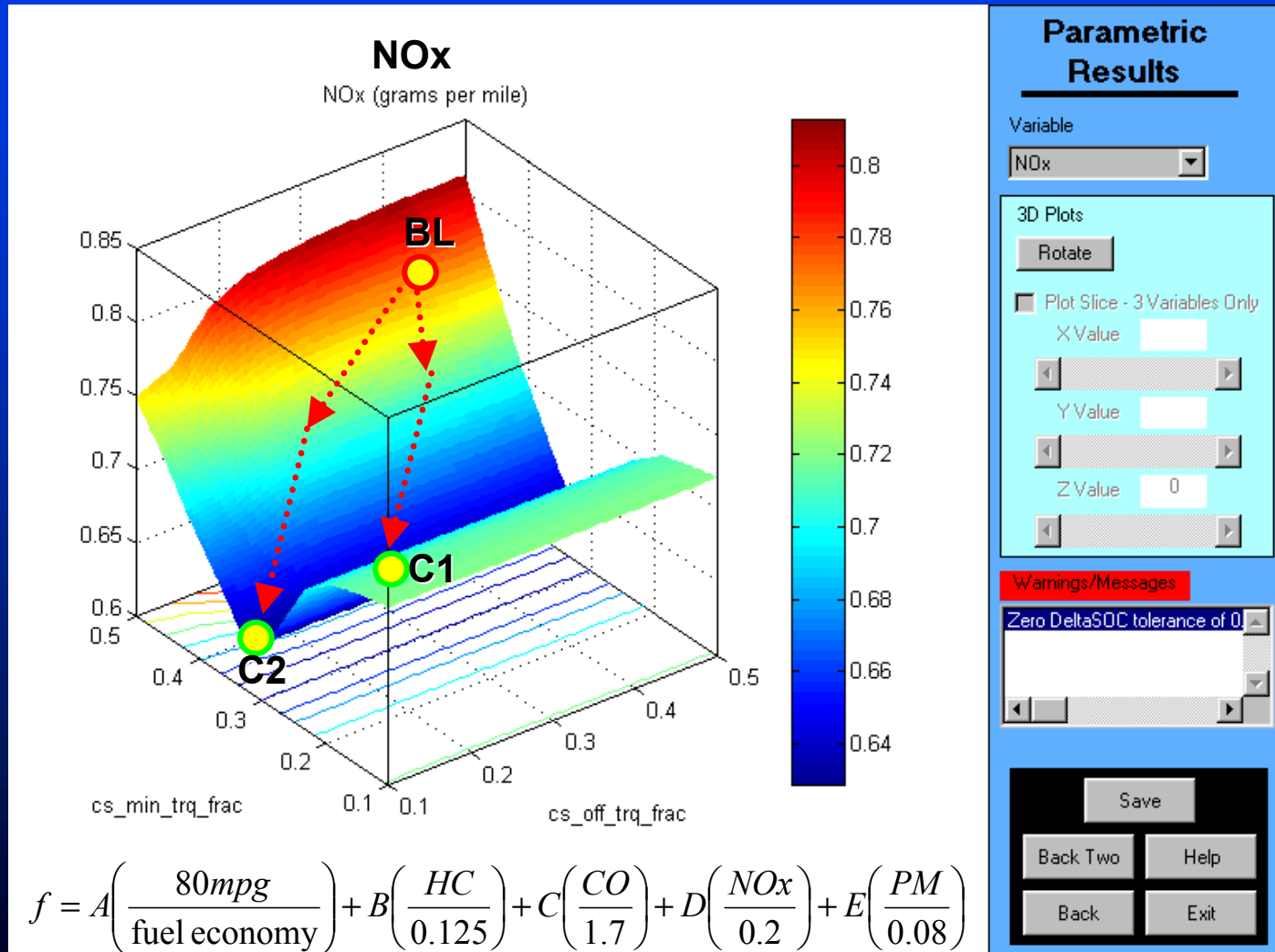
3 Variable Parametric Study



# Optimization Allows Complex Trade-Offs to be Performed Numerically

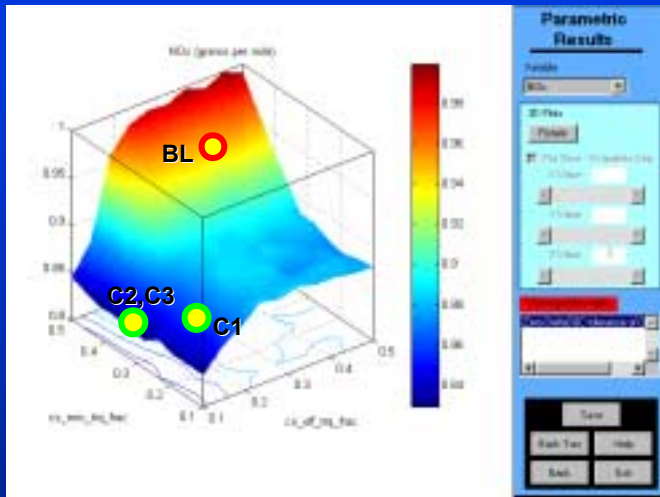


# Control Strategies Have Significant Impact on Emissions and Fuel Economy: Optimization Needed

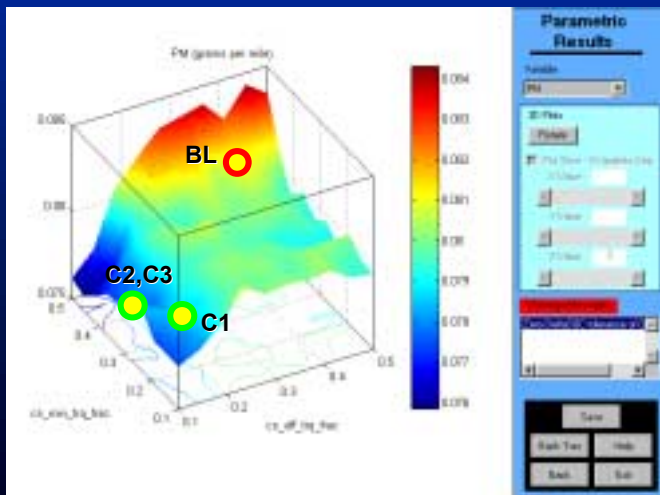
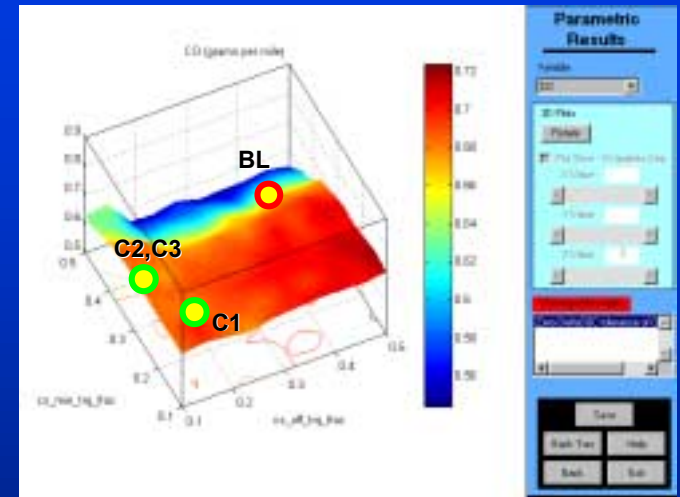




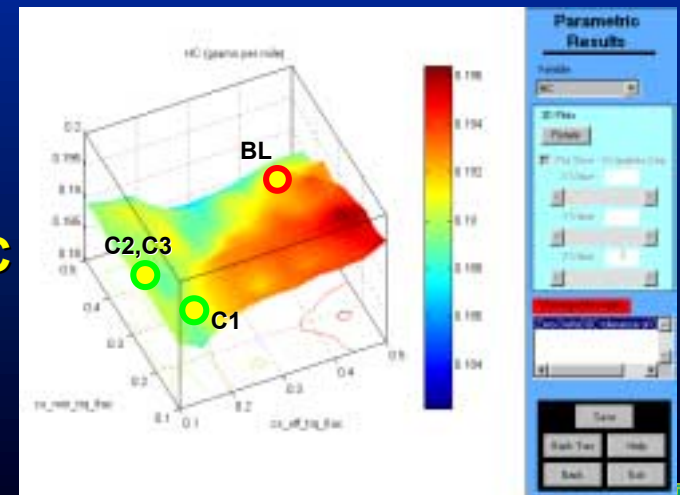
# Even within Emissions Targets there are Trade-offs: Example: Better NO<sub>x</sub>, PM, But Worse CO, HC



NO<sub>x</sub> CO

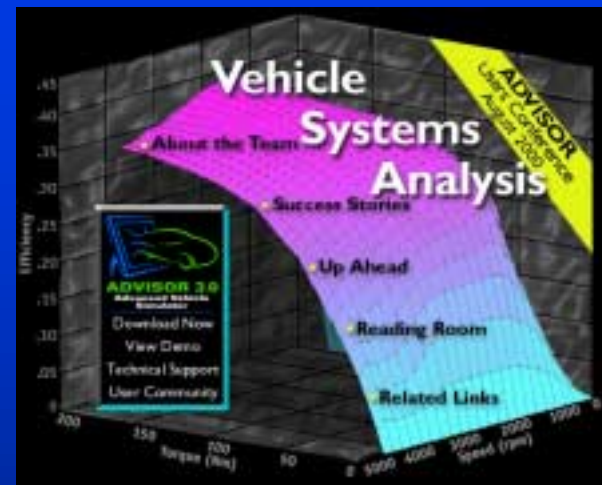


PM HC



# Software Availability on Web

- NREL's Vehicle Systems Analysis web site launched in September 1998
- ADVISOR 3.0 available for free after filling out simple form
- 'Forum' has bulletin area for questions to be answered and files to be shared
- Documentation viewable from web site
- Reading room has all papers and presentations from team

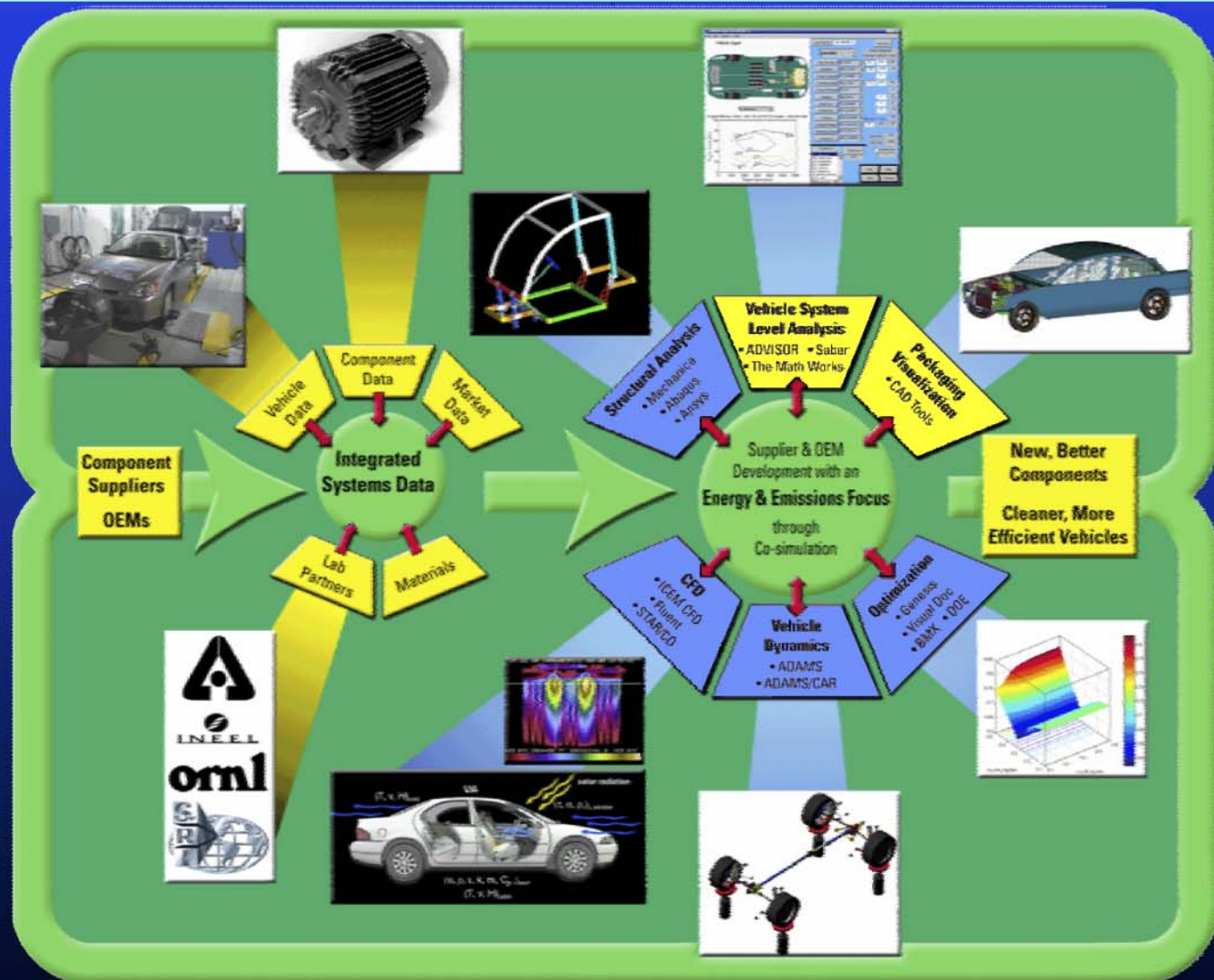


Clockwise: Ken Kelly, Sam Sprik, Keith Wipke, Tony Markel, Valerie Johnson, Aaron Brooker, Terry Hendricks





# Example of Linking with Packaging




# Loading ADVISOR Vehicle into Pro/HEV

Pro/HEV 1.1 - Netscape

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location <http://192.174.54.60/prohev/prohev.htm> What's Related

 NATIONAL RENEWABLE ENERGY LABORATORY  DOE | NREL | ADVISOR

## Pro/HEV

**FILE**

- ▶ [Load HEV]
- ▶ [Save HEV]
- ▶ [Load Defaults]
- ▶ [Clear]

**ANALYSIS**

- ▶ [Configure]

**EDIT**

**Design Summary:**

Vehicle Name:	<input type="text" value="Default small car"/>		
Energy Storage Name:	<input type="text" value="Default ESS."/>		
Wheel-axle Name:	<input type="text" value="Default suspension."/>		
ADVISOR Data:	<input type="text" value="UNKNOWN"/>		

Vehicle Class:	<input type="text" value="SMALL CAR"/>	Number of passengers:	<input type="text" value="5"/>
Wheelbase:	<input type="text" value="2640.0"/> mm	Number of modules:	<input type="text" value="20"/>
Drivetrain Type:	<input type="text" value="SERIES"/>		
Track (front):	<input type="text" value="1440.0"/> mm		
Track (rear):	<input type="text" value="1440.0"/> mm		

Last updated Monday, November 15, 1999 09:29:14

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Contact: NREL, 1617 Cole Boulevard, Golden, CO 80401-3393 [prohev@nrel.gov](mailto:prohev@nrel.gov)

Document Done



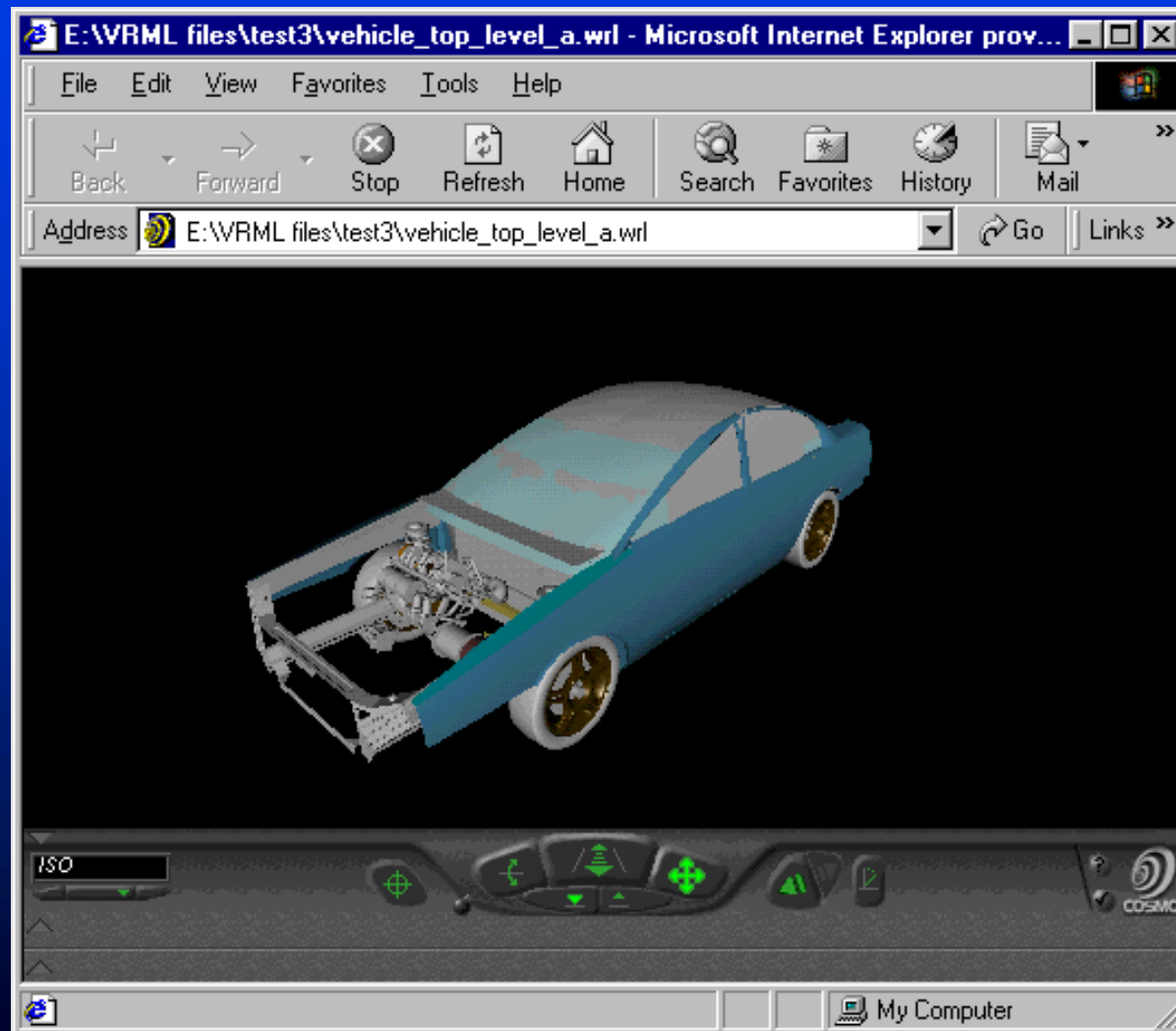
NREL, CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS



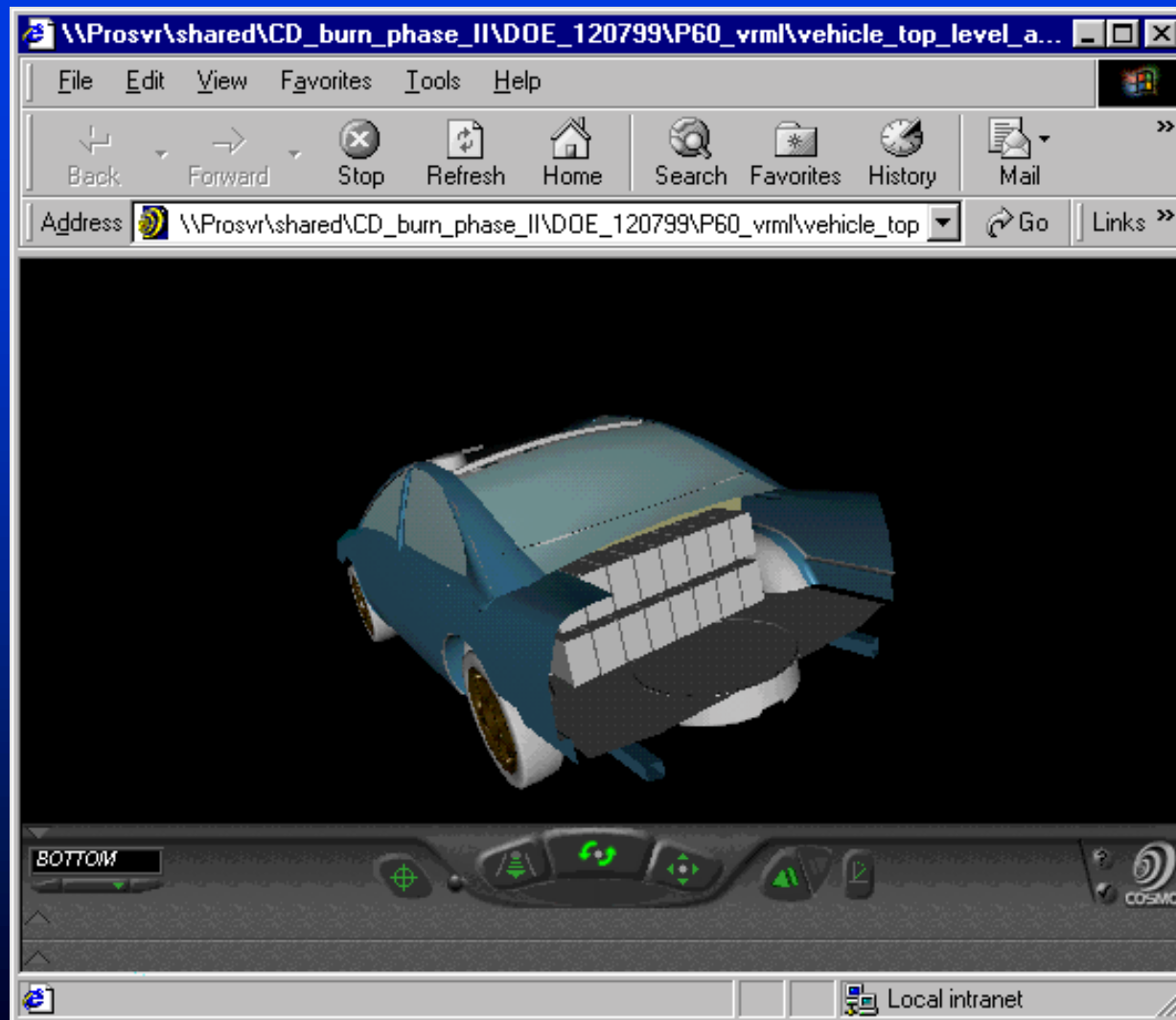




# Visualizing VRML Vehicle in Browser

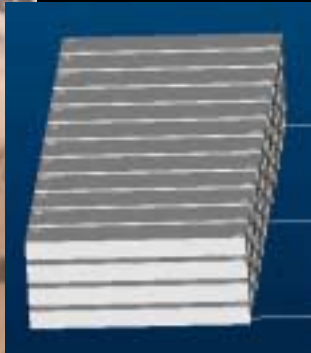


# Visualizing VRML Vehicle in Browser

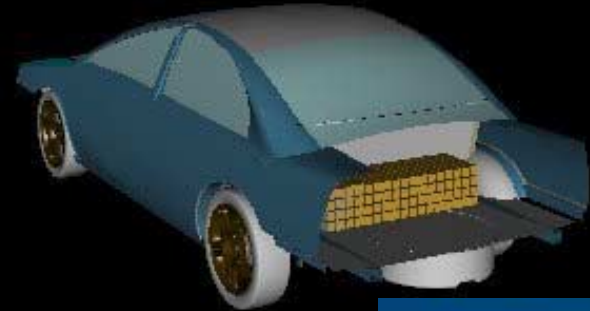


# Battery Packaging Comparison from Previous Study (for illustration purposes)

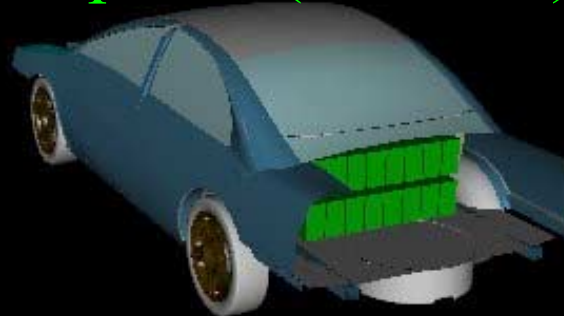
Prius (NiMH)



Battery "A" (Li-ion)

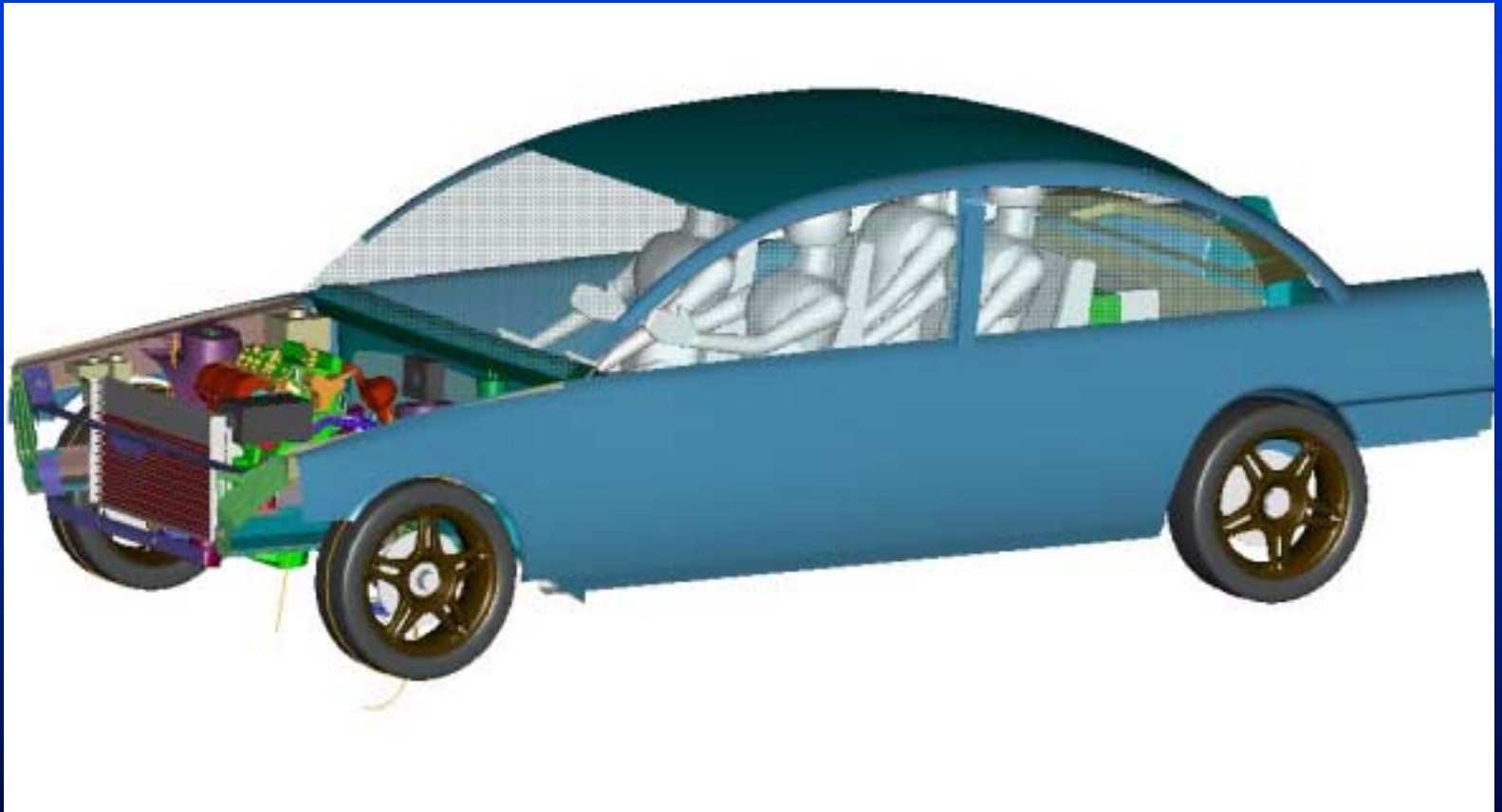


Optima (Pb-Acid)





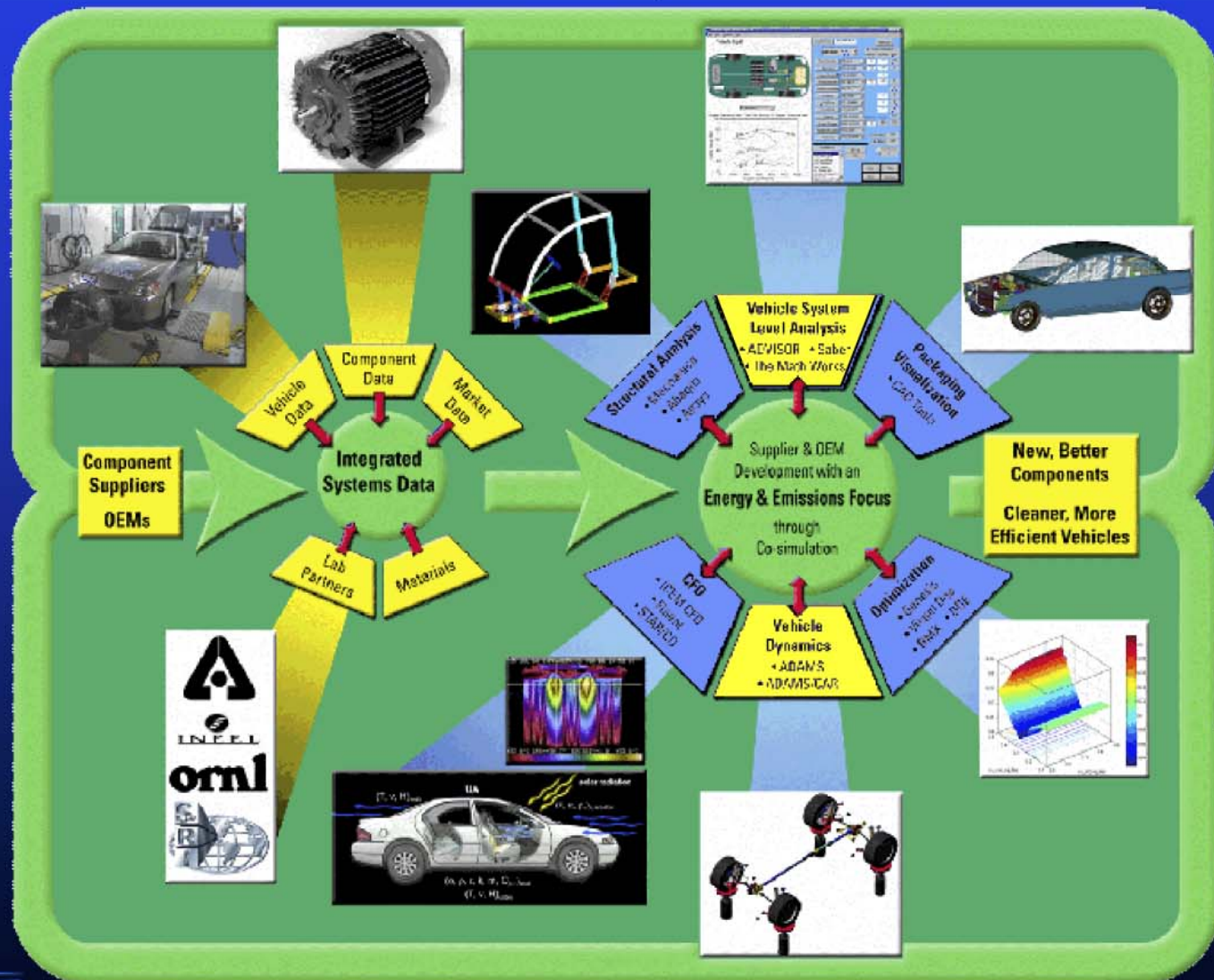
# Full Parametric Vehicle Assembly also Includes Geometry Useful for Many Groups at NREL



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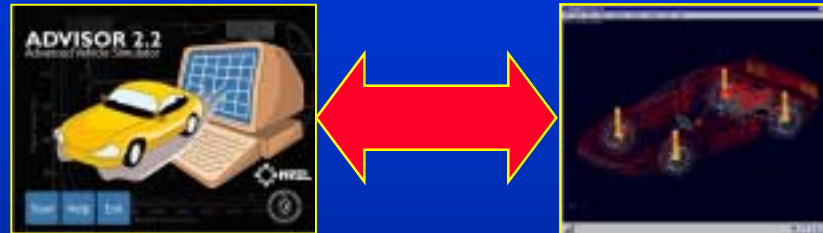
# Linking Systems Level Analysis with Vehicle Dynamics



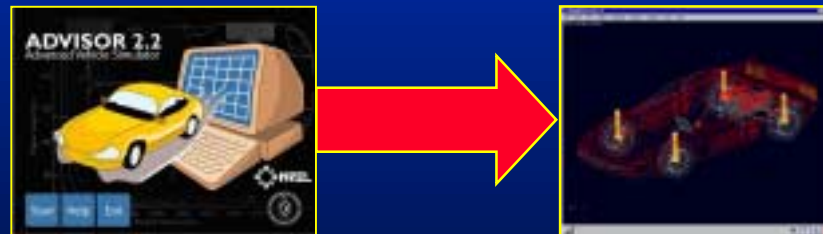
# Outline:

## Interfacing ADVISOR and ADAMS/Car

- Two interface approaches will be used:
  - ADAMS/ADVISOR Co-simulation



- Export to ADAMS/Car



- Each approach has its own advantages and serves different simulation purposes.





# ADAMS/ADVISOR Co-simulation

- ***What?***

- Linking ADAMS/Car full vehicle model with ADVISOR model
- Both ADAMS and Simulink solvers run together
- Information passed back and forth between the two at each time step

- ***How?***

- ADAMS/Car full vehicle model using customized powertrain template
- Modified ADVISOR model to work with ADAMS/Car model





# ADAMS/ADVISOR Co-simulation

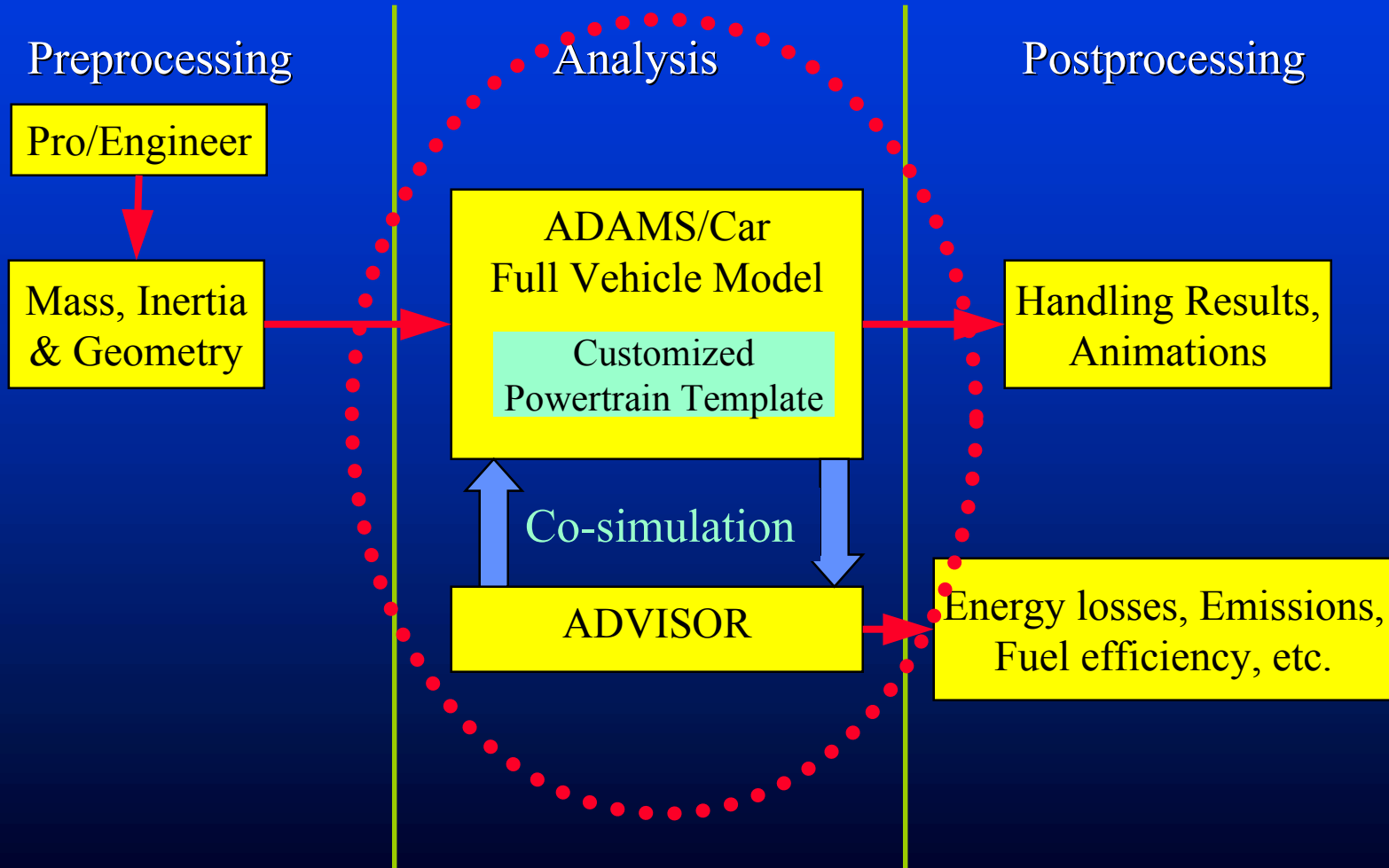
- *Why?*

- Simulate 4WD/AWD powertrains
  - torque split can be actively controlled by ADVISOR
- Vehicle handling/dynamics with new CM from ADVISOR
  - can look at stability issues relating to battery placement
- Calculate energy losses during handling/durability events
  - useful for trying minimizing losses for maximum fuel efficiency
- Integrate accessory loads (like electric power steering) and look at their energy impact vs. performance
- Trade-offs to accurately assess impact of vehicle/component mass reduction and evaluating effect on dynamic performance
- Perform anything you would normally do in ADAMS/Car, but using an advanced powertrain from ADVISOR



# ADAMS/ADVISOR Co-simulation

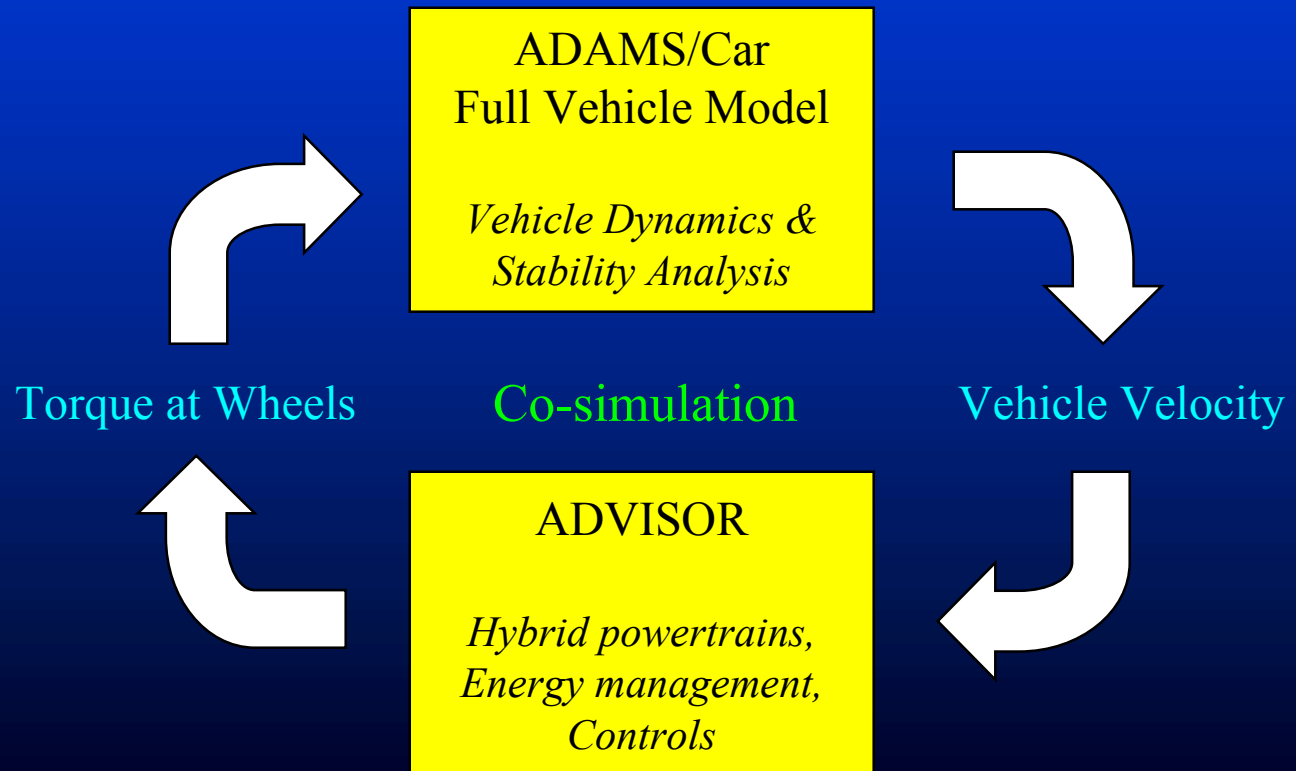
- **Overview**



# ADAMS/ADVISOR Co-simulation

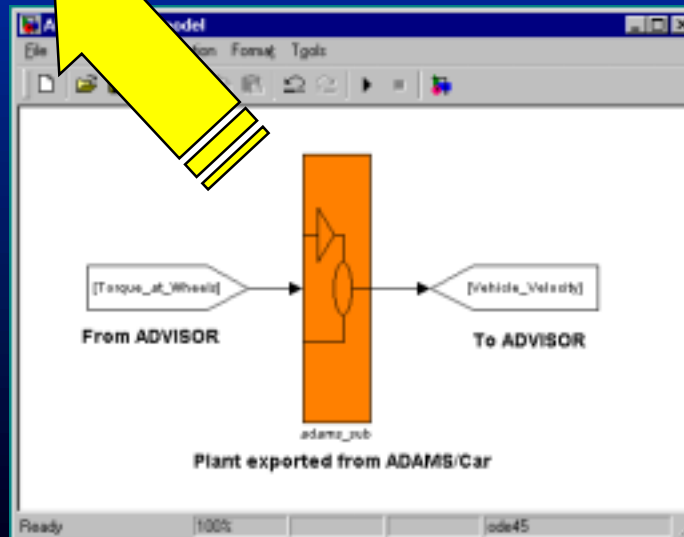
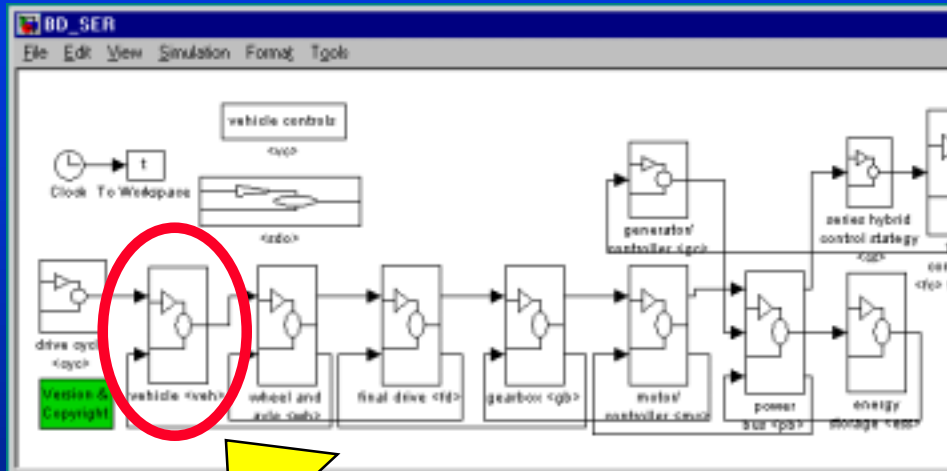
- **Information Flow**

- The major variables exchanged are shown below. Additional information will also be exchanged.



# ADAMS/ADVISOR Co-simulation

- Exporting ADAMS/Car Plant to Simulink*



Block Parameters: ADAMS Plant

MDI/ADAMS Plant [mask]  
Simulate any MDI/ADAMS plant model either in ADAMS/Solver form (.adm file) or in ADAMS/View form (.cmd file)

Parameters

ADAMS install directory  
ADAMS\_exe

User executable (opt: if blank - use standard)  
ADAMS\_exec

Initial Static Simulation Flag  
ADAMS\_static

ADAMS model file prefix  
ADAMS\_prefix

ADAMS/View input names  
ADAMS\_inputs

ADAMS/View output names  
ADAMS\_outputs

ADAMS/Solver in/output IDs  
ADAMS\_u\_y\_ids

Direct feedthrough number  
0

Output files prefix (opt: if blank - no output)  
'aplant\_out'

Output step size  
0.005

Simulation mode discrete

Animation mode batch

Initialization mode automatic

Initialization commands  
0

OK Cancel Help Apply





# Export to ADAMS/Car

- **What?**
  - ADAMS/Car full vehicle model with mass and inertia properties exported from ADVISOR
  - One way information flow to ADAMS/Car
- **How?**
  - Output mass and inertia properties from ADVISOR to ADAMS/Car.
    - Optionally, geometry may be specified in web interface
  - Run standard handling maneuvers in ADAMS/Car

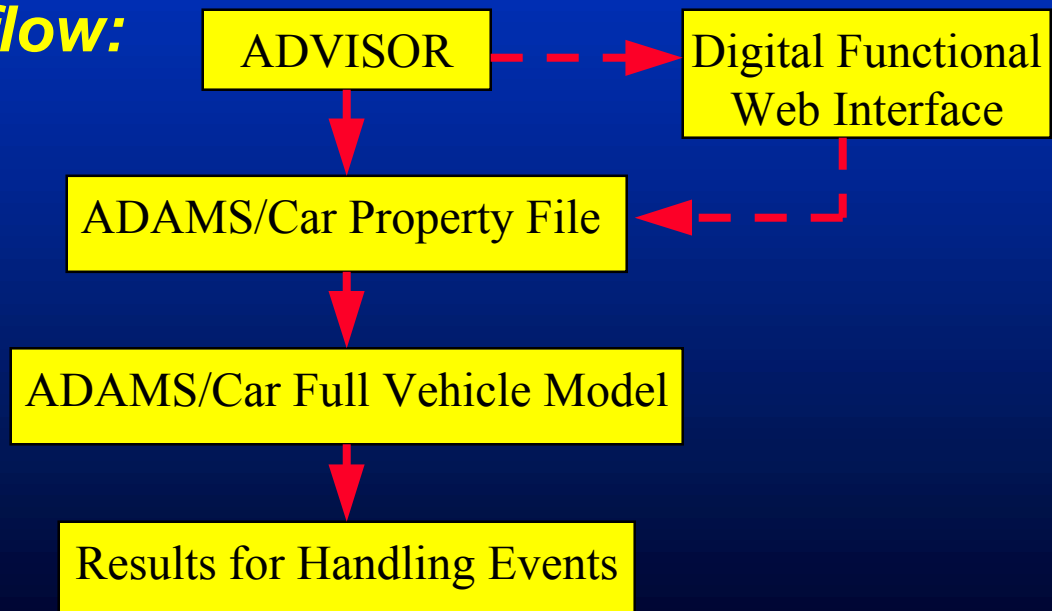


# Export to ADAMS/Car

- **Why?**

- Faster simulations
- Quick estimate of handling performance of hybrid vehicle
  - Example: allows analysis of battery pack location (often a large mass) and effect on handling

- **Information flow:**



# Conclusions

- ADVISOR 3.0 is a user-friendly simulation tool available to the public through the web
  - [www.nrel.gov/transportation/analysis](http://www.nrel.gov/transportation/analysis)
- Widespread usage of the model globally has led to a large database of components and vehicles
- Providing source code to users facilitates better understanding and usage of model
- Validation has been performed and is an ongoing process
- NREL is working with industry to link ADVISOR up to tools they use, such as:
  - Pro/E (visualization, packaging)
  - Visual-Doc (Optimization)
  - SABER (electrical)
  - ADAMS/Car (vehicle dynamics)
  - Flowmaster (detailed thermal modeling)

